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## THE SIGNIFICANCE OF NITRIFICATION AS A FACTOR IN SOIL FERTILITY<sup>1</sup>

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### INTRODUCTION

During the past three decades studies in soil biology have made known many fundamental facts connected with soil fertility. In fact, it is now recognized that the biological factors involved in soil changes are of so much importance that they can not be overlooked in a careful study of any soil problem. The soil biologist, realizing as he does the complexity of factors involved, has been more or less gratified with the progress thus far made. To the non-biological student of soils, or to the layman, the progress made by the biologist in solving fertility problems has not been all that was hoped for. The principal reason for this latter condition lies in the fact that little or no correlation has been shown to exist between the biological conditions as measured in the laboratory, and the facts as observed under field conditions; such, for example, as the crop-producing power of the soil. Some have attributed this lack of correlation, perhaps justly, to the inadequacy of methods employed by the biologists to detect or measure existing conditions. Perhaps a truer explanation is that the biologist, realizing the insufficiency of available knowledge, has been unwilling even to attempt an application of it to practical conditions. On the other hand, the casual student is left to wander unguided in the maze of conflicting statements regarding the role of biological phenomena in fertility problems.

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In an effort to overcome this rather unsatisfactory state of our present knowledge, several soil biologists have recently attempted to show the relation existing between certain biological phenomena and fertility. We may cite as among the most prominent efforts along this line the work of Hiltner and Störmer (9), Russell and Hutchinson (24), Stevens and Withers (26), Lipman (17), Vogel (31), Lyon, Bizzell and Conn (20), Ashby (2), Brown (4), and Kellerman and Allen (13). In many cases a remarkably close agreement has been noted. Sufficient data are in many cases available to indicate rather strongly that the correlation is not incidental.

Of the many factors that have received more or less attention, with a view to ascertaining their relation to fertility, the power to produce nitrate nitrogen or nitrification has received the most study. The reasons for this are evident. In the first place, available nitrogen is more often than any other the limiting element in plant growth. For many years nitrate nitrogen was regarded as the only form available for the metabolism of higher plants, legumes excepted, and it is still looked upon as being the most available source for the major portion of our species of economic importance. We should remember, however, that it is by no means the only form that can be assimilated. In fact, several recent investigations seem to indicate that, at least during certain stages of growth, other forms are used very largely by many important species. The theory offered by Russell and Hutchinson (24) to account for the beneficial effect of partially sterilizing soils upon subsequent plant growth therein, is based upon the assimilation of other forms of nitrogen—largely or wholly ammonia.

It is also an established fact that many species of higher plants flourish under conditions where, so far as present knowledge goes, nitrification is impossible—for example, lowland rice. Under many such conditions it has been shown experimentally that ammonium salts are more beneficial than nitrates. Such conditions, while normal for small isolated areas, do not obtain to an appreciable extent under American agricultural conditions. Besides, any evidence tending to show the utilization of nitrogen in a form other than nitrates, only lends support to the hypothesis here advanced. Hutchinson and Miller (11) and Schreiner and Skinner (25) have given excellent summaries of the experimental data as to the forms of nitrogen available for plant metabolism.

In the following discussion we shall assume that nitrate nitrogen is the form required agriculturally. If other forms normally found in the soil can be assimilated, and we have just mentioned the fact that such is undoubtedly true in certain soils, nitrification is certainly non-essential and may even become economically harmful in that nitrogen in the form of nitrates is readily lost through drainage.

With the above assumption in mind it does not look unreasonable to expect to find a correlation existing between the nitrifying power of a soil and its ability to support vigorous plant growth. In fact, there is abundant evidence now available to show that such a correlation does exist. Vogel (31) is summing up his data on this particular point says: "Die Grösse des Produktionskraft der untersuchten Böden in direktem Verhältnis steht zur Grösse der nitrifizierenden Energie." Likewise Lipman (17), after presenting evidence to show the existence of the above mentioned correlation, says: "I believe that a soil's nitrifying power, whether it be the cause or effect, is one of the prime factors in determining a soil's power to produce." Ashby (2), Stevens and Withers (26), Given (8), Brown (4), and Kellerman and Allen (13) also have called attention to the association of high nitrifying power and high productivity. In Table 1 the writer also submits evidence to show that such a correlation exists in soils studied by him.

These results were secured from plots all located on the same soil type and of as uniform character as could be secured. The greatest distance between any two plots was not more than 85 yards. The nitrifying power of the various plots was tested by several different methods, but gave uniform results. The figures reported are for only one method and represent the average of 4 analyses for 1913 and 5 for 1914. It is not necessary to enter into any description of methods used or of other characters of the soil, except to say that the differences exhibited have been brought about either by varying the cropping system or method of treatment. As mentioned above, the soil was of uniform character when the present system of treating was begun 25 years ago. We would call special attention to a comparison between Plots 9 and 10, 17 and 18, and 22 and 23, the two plots in each instance adjoining and seeded to the same crop. The only difference in each case was an annual application of stable manure to one and nothing to the other. Such evidence seems to indicate clearly one of three things; high fertility is the result of a high nitrifying power; high nitrification is a result of high fertility; or both are the result of common factors.

In none of the above-mentioned papers does the author attribute the correlation definitely to any one of the three possibilities. However, the casual student, perhaps unfamiliar with the facts and realizing the rôle played by nitrifying processes in rendering nitrogen available, is likely to conclude that fertility is more or less limited by the processes of nitrification. In fact, the statements quoted above would indicate that soil biologists themselves believe such to be true. Certain facts brought to light in connection with other investigations carried on by the writer during the past few years, bear directly upon the significance of this correlation. In

the following pages it is proposed to present these facts together with a general review of investigations, reported by several others, which are directly connected with the same problem.

In this discussion we shall use the term *nitrification* in its correct sense: namely, to mean the oxidation of ammonia nitrogen (or other simple nitrogenous compounds if such be possible) to nitrite nitrogen and thence to nitrate nitrogen or, if possible, directly to nitrate nitrogen. The hydrolytic and oxidation processes through which ammonia is liberated from the protein molecule or other complex compounds is often wrongly included in the processes of nitrification.

It is not the wish to detract one iota from the value or even necessity of nitrification as a factor in soil fertility. We believe, however, and shall attempt to show that fertility in normal agricultural soils, *in so far as nitrate nitrogen is the limiting factor*, is limited by those analytical processes necessarily preceeding nitrification rather than by nitrification itself.

With the exception of the small amounts of nitrates and ammonium salts, and a few other less important forms applied as fertilizers, all the nitrogen utilized agriculturally (legumes excepted) must be derived from organic sources. As far as our knowledge now goes regarding the transformation of organic nitrogen into nitrate nitrogen, the processes of nitrification must be preceded by those of ammonification or the splitting up of the complex molecules containing nitrogen with the ultimate liberation of ammonia. These facts being true, in order to prove in any given case that productivity or fertility is not limited by nitrification, it is necessary only to show that the processes of ammonification do not proceed more rapidly than those of nitrification.

On first thought it might seem that this would be comparatively easy, it being necessary only to show whether or not ammonia nitrogen accumulates. On the one hand, if ammonia nitrogen does accumulate we would conclude that nitrification had not been proceeding as rapidly as ammonification. This, however, is not necessarily true. So far as the writer is aware, no cultivated soil has ever been reported that did not contain more or less ammonia nitrogen. Sometimes the quantity is very minute. In fact, it is rarely ever taken into consideration by students of soil fertility. If past methods of analysis can be relied upon, the quantity of nitrogen present in soil in the form of ammonia may sometimes exceed that present as nitrates (3, 16). That ammonia nitrogen is always present, however, is true. We shall endeavor to show that this is true regardless of the vigor of the nitrifying flora and that the activity of these organisms, as well as it can be measured, controls the quantity of ammonia nitrogen present only within certain limits. It appears, then, that for some physi-

cal, chemical or biological reason, or combination of reasons, the nitrifying organisms do not nitrify the last traces of nitrogen present as ammonia. The quantity of ammonia nitrogen present where nitrification is active varies with different soils and with the same soil under different conditions. Furthermore, when a quantitative determination of ammonia is made by the methods now in vogue we do not know that the results secured represent ammonia nitrogen existing as such in the soil, or that the ammonia nitrogen existing in the soil is liberated quantitatively. Therefore, we can not rely solely upon the presence of determinable quantities of ammonia nitrogen as indicating inactivity on the part of the nitrifying flora.

On the other hand, the absence of an accumulation of ammonia is beset with even greater difficulties of interpretation, owing to the various ways in which it may disappear from soils other than through the processes of nitrification. For example, we know that certain soil fungi and bacteria utilize ammonia nitrogen in their metabolism and may also possess the ability to transform it into other compounds without assimilation, though we are not aware that such has ever been shown. The same is true of certain higher forms of plants. Also, we know that the various salts of ammonia are, as a rule, readily soluble in water and hence may be lost through drainage. We also know that soils seem to possess the ability to fix ammonia nitrogen in some rather stable form so that it can not readily be driven off by methods usually employed for its quantitative determination (22). Lastly, it may be lost by volatilization. The quantities which are removed from the sphere of quantitative determination, by these different agencies are at the present time impossible of determination. Therefore, the absence of determinable quantities of ammonia nitrogen does not necessarily signify the equal rapidity of the process of ammonia and nitrate formation.

In order to be absolutely certain of an answer to the question under discussion we should, perhaps, be able to measure the influence of each of the above-mentioned factors separately. Obviously, such is impossible. We believe, however, that by combining certain of these factors and measuring their gross influence we should be able to secure sufficient evidence to show, beyond reasonable doubt, the validity of our hypothesis. For example, if it can be shown that in normal cultivated soils nitrification is active; that in such soils there is no abnormal accumulation of ammonia nitrogen; and that by eliminating the processes of nitrification, otherwise not changing the soil, we secure an abnormal accumulation of ammonia nitrogen, we believe sufficient data will be available to bear out our assumption. In the following pages we shall attempt to show such to be possible. In so doing we shall not attempt to report all available data. Only enough will be given in each instance to bear out the points we wish to emphasize.

## THE UNIVERSAL EXISTENCE OF ACTIVE NITRIFYING ORGANISMS IN CULTIVATED SOILS

As mentioned above, in order to show that the processes of nitrification do not limit nitrate accumulation in normal cultivated soils it is of prime importance to show the existence of active nitrifying organisms in such soils. We admit that much of the evidence upon which we must base our conclusions may be unreliable. Owing to the difference of opinion regarding desirable methods for obtaining such data it is not for any one to say which are and which are not reliable. The only impartial method under such conditions is to take all evidence at face value unless it is obviously in error. A few general precautions, however, are necessary in drawing far-reaching conclusions from the available data in this particular instance.

For example, there are many data on record which in light of present knowledge were secured under conditions practically if not entirely inhibitory to the processes of nitrification. Often nitrifying activity has been reported zero when other data accompanying or available show that active organisms were present. As an example of this latter condition we may mention the reporting of activity as zero when the soil at the beginning of the experiment contained large quantities of nitrate nitrogen. With the possible exception of the semi-arid soils of our western states marked accumulation of nitrates in soils is impossible other than through the processes of nitrification. Yet this unquestioned fact is so far overlooked that a soil's nitrifying ability is reported zero unless, under the particular experimental condition to which it is subjected, it shows an accumulation of nitrate.

Likewise, other data are on record secured undoubtedly under conditions much more favorable for the processes concerned than those under which the soil *in situ* existed.

Still other soils are reported as devoid, deficient, or to possess good nitrifying power, the only basis for such assertions being the soil's relative ability to accumulate nitrates under field conditions. In such instances no cognizance is taken of the absolute absence of any definite knowledge as to the quantities of nitrates removed from the sphere of quantitative determination by the various active physical, chemical, and biological factors.

In this paper we have used as a criterion of the existence of active nitrifying organisms in a soil a measurable increase in nitrate nitrogen under the experimental conditions to which the soil was subjected. An effort has been made to review all the instances in American literature where such a criterion could be applied. It is not necessary to cite the literature or to mention the number, character, etc., of those soils showing nitrification. It is sufficient to say that they cover a very wide range of

normal conditions, soil types, states of fertility, territory (every state), as well as a large number of experimental conditions. In this study we have located but one instance worthy of consideration wherein the absence of nitrifying activity in soils approaching normal cultivated condition has been reported, namely, the work of Stevens and Withers (27). It is true that Lipman (18) reports 3 soils which failed to nitrify, but two of these were uncultivated and the third was impregnated with black alkali. Sackett (29) also reports 4 out of 55 that failed to nitrify (5): three of these were uncultivated and the fourth was killed by niter trouble. There are also a few other instances on record, but in all cases the soil was uncultivated or had been studied because of some very marked abnormal condition.

Stevens and Withers (27) report a study of 40 soils, 60 per cent of which failed to nitrify. Löhnis and Green (19) have pointed out that the failure to observe nitrification in this instance was probably due to the methods employed. In support of this explanation we call attention to a report several years earlier by Withers and Fraps (32) in which 15 soils from the same state were studied, all of which nitrified. Kellerman and Robinson (14) also report a study of 30 soils from North Carolina, all of which nitrified. In a later report by Stevens and Withers (26), in which 79 soils were studied, they summarize as follows: "Every soil showed some nitrification by one or other of the methods, thus proving that in every soil there were living nitrifying organisms. Every method in one or more instances failed to show nitrification, thus proving that no method which we used afforded satisfactory conditions for the activities of the complexes in all the soils." It seems evident therefore, that while Stevens and Withers failed to secure nitrification in a large number of soils, such failure was probably due to the particular experimental condition and not to the absence of active organisms.

It may be argued that nitrification is absent or impossible in acid soils, but as Temple (30) has pointed out this does not hold true when organic sources of nitrogen are used, and under natural conditions the source is always organic.

From the evidence now available it seems, then, that all normal cultivated soils possess nitrifying organisms at least capable of becoming active. Furthermore, the facts presented above, together with others to follow, coupled with the enormous amount of data showing the presence of appreciable quantities of nitrate nitrogen in soils, the only source of which could be through the processes of nitrification, indicate rather strongly that these organisms are active in their normal habitat.

#### AMMONIA NITROGEN CONTENT OF SOILS

Reliable data as to the quantities of ammonia nitrogen present in soils are very meagre. This lack of data is due to the difficulties attending an



accurate determination. As has often been pointed out, ammonia nitrogen is split off from many of the decomposition products of protein nitrogen with relative ease by the quantitative methods in use. Since decomposition is almost constantly taking place, such compounds are perhaps universally present in soils. Nothing, however, is known regarding the quantities. The ammonia nitrogen recovered by any method liberating such nitrogen would be correspondingly too high. Russell (22) also has pointed out, as mentioned above, that soils possess the ability to fix ammonia in such a manner that it is difficult to liberate. Potter and Snyder (21) have recently reviewed the question of ammonia determination in soils, and if we are to accept their views, we are forced to the conclusion that none of the data now available are even comparatively, much less quantitatively, accurate. The evidence submitted by Potter and Snyder, however, tends to show that figures secured as such herein reported, are approximately 50 per cent too high. With these facts in mind we shall assume that the figures here used are comparative. Many figures have been reported which, because of analytical methods, such as permitting of the possible accumulation of ammonia after soil samples were drawn, are obviously not comparative. We have, therefore, selected only such instances as seem, upon evidence accompanying them, to be as free from such objections as any obtainable.

As mentioned above, ammonia nitrogen is usually not taken into consideration by students of soil fertility and is referred to in text books as existing only in traces or very minute quantities. Stockbridge (28) gives the figures as varying from .00014 to .001 per cent with an average of .00057 per cent. Russell (22) reports figures varying from a trace to 7 parts per million. Figures secured by investigators in this country have usually been higher, due, possibly, to a difference in analytical methods or to the ability of our soils to prevent the oxidation of higher percentages. Lathrop and Brown (16) report from 16 to 28 parts per million, the figures for ammonia nitrogen being materially higher than the nitrate nitrogen figures. Brown (3) reports from .00095 to .00135 per cent, the ammonia nitrogen again exceeding that present as nitrate nitrogen in most instances. Jodidi (12) gives quantities varying from .00064 to .001508 per cent. (Figures for wet soils given in this paper can not be taken into consideration since the soil was held for a year before being analyzed.) By use of the magnesium oxide distillation method the writer (7) has shown the quantity under several differently treated plots to vary from .00038 to .00315 per cent with an average of several different determinations for the individual plots varying from .00116 to .00159 per cent. The results secured from several plots are reported in Table II. These data were secured by thoroughly mixing 12 different borings from the individual plots and distilling the ammonia off from an aqueous ex-

tract of the soil in presence of magnesium oxide. Determinations were made as soon as the soil was brought to the laboratory, 100 gm. being used in each instance and duplicate determinations made. The low figures of September 12 were secured after a long extremely dry period when there was perhaps not enough moisture in the soil for bacterial activity.

Kelly (15) has reported the ammonia nitrogen in a number of soils, in many of which it is claimed nitrification is practically absent. The quantities reported vary from 2 to 69 parts per million. The average for uncultivated soils, where nitrification is supposedly absent (page 10) is about 18 parts per million and for cultivated soils (page 13) approximately 13 parts per million. In the former case the ammonia nitrogen is reported as being abnormally high, yet the figures do not vary materially from those reported from normal soils on the continent or from the cultivated soils, where nitrification, according to the quantity of nitrate nitrogen present, was evidently active.

Hutchinson (10), without giving any experimental data, says that in soils studied by him at temperatures of 15° to 18° C., nitrification takes place just as rapidly as ammonification, whereas at 25° to 30° C. ammonia accumulates and may become so abundant as to inhibit nitrification.

Abbott, Conner and Smalley (1) report as the average ammonia content for a number of plots, figures varying from 12.6 to 20.8 parts per million, or as average of all plots at different dates, figures varying from 6 to 37.1 parts per million.

From the above results, it seems evident that under normal agricultural conditions we never get a marked accumulation of ammonia nitrogen; however, conditions may sometimes become such that we do.

#### WILL SOILS RETAIN AMMONIA NITROGEN BEYOND THAT NORMALLY PRESENT?

In solving the problems before us it is necessary to show in some way that the low quantities of ammonia nitrogen normally present are not due to losses other than by transformation into nitrate nitrogen. It is obviously impossible to measure the various losses; therefore, we must use other means. If we can show that soils normally low in ammonia nitrogen possess the ability to hold large quantities and that in such soils we can eliminate the processes of nitrification (otherwise permitting normal losses), and secure such an accumulation, we believe we have the desired information.

It is common knowledge among soil biologists that when easily decomposable organic nitrogenous compounds are added to the soil we get large accumulations of ammonia nitrogen. However, such experiments are usually continued for only a short time and unless nitrifying organisms are

eliminated, the ammonia nitrogen thus formed is usually oxidized to nitrate nitrogen. The writer has used various methods for eliminating nitrification and in all cases it has been found that the large initial ammonia nitrogen will persist for 6 months or longer without any large decrease in quantity. Perhaps we are not justified in drawing conclusions from such abnormal conditions, since, if the processes of formation were more gradual, the disappearance might be as rapid as the formation. In this connection we call attention to the large amount of data published by Russell and Hutchinson (24) and their students (23), where no initial addition of nitrogen was made. They have demonstrated that when for any reason the processes of nitrification are eliminated, without at the same time eliminating ammonification, there is a gradual accumulation of ammonia nitrogen that will, as far as experimental data go, persist indefinitely. This cannot be due to any deep-seated change rendering the ammonia nitrogen less available for nitrifying organisms, since when they are reintroduced or, as has been shown by the writer (6), the antiseptic action of the inhibiting agent removed, the ammonia nitrogen falls to its original level with a corresponding increase in nitrate nitrogen. These results have been verified in a number of laboratories. The writer has also carried out similar experiments under field conditions, where soils were subjected to all the influences tending to cause losses of ammonia nitrogen, and has found the same conditions to exist.

In Table III, two series of such results are reported. The two are the same except that in B there was an addition of cottonseed meal. The plots were treated June 12, 1913, with increasing quantities of  $\text{CS}_2$  (expressed as c.c. per sq. ft.) as follows: No. 1,—0; No. 2,—5; No. 3,—10; No. 4,—25; No. 5,—50; No. 6,—100. The analyses here reported were made on July 25 in case of A and August 4 in case of B. The quantities of nitrate nitrogen as here reported, and as observed in subsequent analyses show that the processes of nitrification were only temporarily checked. Nevertheless, the data show that this soil is capable of holding much larger quantities of ammonia nitrogen than is normally contained. The results of Kelly, cited above, also show that soils are capable of holding much larger quantities than are usually present. We do not believe, therefore, that the low quantities of ammonia nitrogen usually found in soils are due to the inability of the soil to retain larger quantities.

#### RELATION BETWEEN AMMONIA CONTENT AND NITRIFYING POWER OF SOILS

If, as has been shown above, the elimination or checking of nitrification causes a corresponding increase in ammonia nitrogen, we can see no reason why, if there is normally a deficiency in nitrification, we should not likewise detect increasing quantities of ammonia nitrogen. In other

words, we should, it would seem, find a relation between ammonia content and nitrifying power.

In this connection we call attention to Russell's conclusions (22) that: "As there is no tendency for ammonia to accumulate, it follows that the rate of nitrification must be greater than that of ammonia production, and in normal soils is limited by this rate." Also, to the concluding remarks of Kellerman and Allen (13) regarding nitrification in arid regions that: "Lack of nitrification, therefore, will not be a limiting factor in crop production . . . . Humification studies are probably of paramount importance."

In laboratory experiments, in testing the nitrifying power of soils with an initial addition of easily decomposable organic nitrogenous compounds or of ammonia nitrogen, any subsequent analyses made prior to complete nitrification will reveal an inverse ratio between ammonia content and nitrifying power. In fact, a quantitative analysis of the ammonia nitrogen will give us, in most cases, as accurate knowledge regarding the nitrifying power as will a determination of nitrate nitrogen. The latter, however, under conditions where losses of nitrate nitrogen are eliminated, is regarded as giving the most accurate data obtainable as to the activity of the nitrifying flora under that particular condition.

If we consider, as Kelly (15) does, that the nitrate present in the soils reported by him is a criterion of nitrifying activity, then we are forced to the conclusion that no such relation as suggested above exists. Kelly reports analyses of 41 soils and of 10 of these containing 10 or more parts per million of *nitrate* nitrogen, 100 per cent contain 10 or more parts per million of *ammonia* nitrogen. Of 31 containing less than 10 parts per million of *nitrate* nitrogen only 84 per cent contain 10 or more parts per million of *ammonia* nitrogen. Or, as pointed out above, in those soils in which nitrification is supposed to be active, the average ammonia content is about 13 parts per million, while in those in which it is supposed to be very deficient or absent the content of ammonia nitrogen is only about 18 parts per million. With the methods of analysis used, these differences are slight. To offset these differences we find that of all the soils reported by Kelly, No. 329 probably contained the most active nitrifying flora. Yet, on the average it contained the largest quantities of ammonia nitrogen. The low ammonia nitrogen content of soils here reported could not be due to the inability to retain larger quantities. Subsequent experiments show that in the presence of an addition of dried blood the ammonia content reached the enormous quantity of 1500 parts per million. In the absence of any addition of nitrogen, checking or eliminating nitrification by the use of heat,  $CS_2$  or toluol caused a steady increase in ammonia nitrogen until nitrification again set in. In one instance this increase continued for 200 or more days, the quantity reaching 268 parts per mil-

lion. It is also worthy of note that the aerated soil containing the least amount of nitrate nitrogen (1 part per million) also contained the least amount of ammonia nitrogen (4.2 parts per million). While Russell gives us no indication of the relative nitrifying power of the soils reported by him, we have every reason to believe that they varied widely. Still with the exception of No. 7-2 the variation in ammonia nitrogen content was within the limit of experimental error. From results reported elsewhere (see Table 1) and also by Ashby (2) on other Rothamsted plots we would certainly expect to find the highest nitrifying power in soil from Plot 7-2, yet it contained materially higher ammonia nitrogen than any other. The same argument applies to the results reported by Brown (3) and Jodidi (12). In the case of the Pennsylvania Experiment Station plots, Given (8) has shown that there are wide variations in the nitrifying powers of those differently treated. Likewise, Brown (4) reports similar conditions for Iowa Experiment Station plots. In neither case, however, is there any marked accumulation of ammonia in one plot over another.

Fortunately, the writer has secured data on a number of different plots both as to ammonia content under field conditions and nitrifying power measured according to best available methods. Some of the results thus secured are presented in Table II.

We would call special attention to Plots 17 and 18 adjoining and planted to the same crop for the past 25 years. They have given us consistently the lowest and the highest nitrifying power, respectively, of any soils studied. A study of these data leads us to the same conclusion as was arrived at above. That is, as far as we are able to detect, no relation exists between the ammonia content of soils and their nitrifying powers.

#### RELATION BETWEEN AMMONIA NITROGEN CONTENT AND YIELD

If there is a correlation between nitrification and yield but no correlation between nitrification and ammonia nitrogen content, we should, of course, not expect to find any existing between ammonia nitrogen content and yield. However, if low fertility is a result of low nitrification and the processes of ammonification exceed those of nitrification, then we should expect to find low yielding power associated with high ammonia nitrogen content. Fortunately, we have considerable data with regard to these two conditions.

Selecting the most marked variations, with regard to yield, reported by Brown (3) and comparing these with ammonia nitrogen content we have the results given in Table V.

In Table IV are given the ammonia nitrogen contents reported by Russell together with the yields from the same plots for that particular year and also the averages for the past 60 years.

Summarizing the results secured by the writer as to the relation between ammonia nitrogen content, yield, and nitrifying power, we have the data presented in Table I.

A study of the data here presented, secured from widely different localities, soil types, and variations in productivity, convinces anyone of the absence of any correlation between yield and ammonia nitrogen content.

As pointed out before there is evidently a correlation between nitrifying power and yield but not between any other two factors under consideration. Similar studies have been made upon a number of isolated spots similar to those reported by Lipman (16). The results secured on soil from such spots conform so nearly with data already presented that they will not be given.

#### SUMMARY

In the foregoing pages we have endeavored to show that productivity in non-productive soils, in so far as nitrogen is the limiting factor, is not limited by the processes of nitrification. In support of this hypothesis we have submitted evidence to show:

I. That all cultivated soils approximating normal conditions, contain active nitrifying organisms.

II. That in such soils these organisms transform ammonia nitrogen into nitrate nitrogen as rapidly as it becomes available. In support of this contention it has been pointed out:

(a) That in such soils there is no accumulation of ammonia beyond a fairly constant equilibrium maintained between those factors tending to the formation and those tending to the disappearance of ammonia.

(b) That this failure to accumulate is largely due to the transformation of ammonia into nitrates. This statement is based upon the following facts:

1. Soils will physically and chemically retain much larger quantities of ammonia than they normally contain.

2. When nitrification is impossible, because of some unfavorable condition, ammonia does accumulate.

3. When the nitrifying organisms in such soils regain their activity, the ammonia thus accumulated is rapidly transformed into nitrate nitrogen.

III. That in cultivated soils there is no correlation between ammonia content and nitrifying power, whereas there should be an inverse ratio if ammonia is formed more rapidly than nitrification is proceeding.

IV. That there is no correlation between ammonia content and productivity, whereas an inverse ratio should exist if low yielding power is a result of low nitrifying power.

We believe, therefore, that while there is usually a correlation between nitrifying power and productivity, it does not imply that the processes of nitrification are responsible for yield or that yields on non-fertile soils are limited by the process of nitrification. As to whether high nitrifying powers are the result of high fertility or that both are the result of common factors, there are very few data to indicate. Since it is not impossible that both factors depend upon available plant-food, we would call attention to the work of Lipman (17) who has detected a relation between yields and certain available inorganic elements, also to the work of Fraps (5) who has detected a relation between nitrogen content of soils and their nitrifying powers.

#### CONCLUSIONS

We believe from the data to which attention is here called one is justified in the following generalization: that while nitrification is perhaps a valuable and even essential asset in fertility it probably does not, under normal conditions, become a limiting factor in productivity.

TABLE I  
RELATION BETWEEN AMMONIA-NITROGEN CONTENT, NITRIFYING POWER AND YIELD

Plot No.	1913			1914		Average Yield for 25 Years
	NH <sub>3</sub> -N.	N. P.	Yield	N. P.	Yield	
9	.....	.....	8.83 bu.	43.1	20.09 bu.	9.55 bu.
10	.....	.....	16.90 bu.	107.2	26.37 bu.	16.72 bu.
13	1.53	71.9	1508 lbs.	71.5	377 lbs.	.....
20	1.27	94.7	4810 lbs.	91.5	1177 lbs.	.....
17	1.41	46.4	6.96 bu.	39.2	28.78 bu.	20.35 bu.
18	1.47	120.2	19.22 bu.	124.2	33.89 bu.	35.78 bu.
22	1.31	114.6	3042 lbs.	104.4	1482 lbs.	4923 lbs.
23	1.16	79.4	1339 lbs.	71.0	910 lbs.	2996 lbs.
21	1.59	104.5	17.44 bu.	107.2	28.41 bu.	18.54 bu.
29	1.37	116.6	16.79 bu.	.....	29.56 bu.	15.72 bu.
30	1.44	127.0	22.53 bu.	.....	28.17 bu.	19.58 bu.

NH<sub>3</sub>N = Mg. Nitrogen as Ammonia per 100 gm. soil.

N. P. = Mg. NO<sub>3</sub> formed per 100 gm. soil.

Note:—Cropping system for Plots 9, 10, 21, 29 and 30 continuous wheat; 17 and 18 continuous corn; 22 and 23 continuous timothy; 13 and 20 6-year rotation of corn, oats, wheat, clover, timothy, timothy. Plots 10, 20, 18, 22 and 30 have received annual application of stable manure; 29 annual application since 1909.

TABLE II  
COMPARISON BETWEEN AMMONIA NITROGEN UNDER FIELD CONDITIONS AND  
NITRIFYING POWER OF SOILS FROM DIFFERENT PLOTS

Plot No.	7-11		8-12		9-12		11-4		12-22		Ave. '13		Ave. '14
	NH <sub>3</sub> -N	N. P.	NH <sub>3</sub> -N	N. P.	NH <sub>3</sub> -N	N. P.	NH <sub>3</sub> -N	N. P.	NH <sub>3</sub> -N	N. P.	NH <sub>3</sub> -N	N. P.	
13	....	109.4	1.44	56.7	.45	79.2	2.97	42.4	1.25	....	1.53	71.9	71.5
20	....	95.8	1.70	128.0	.45	82.4	1.68	72.6	1.25	....	1.27	94.7	91.5
17	....	67.5	1.13	82.5	.45	28.0	3.15	7.6	0.92	....	1.41	46.4	39.2
18	....	125.2	1.50	146.3	.45	93.2	2.22	116.2	1.70	....	1.47	120.2	124.2
21	....	101.1	1.44	133.0	.38	95.6	2.04	88.3	2.50	....	1.59	104.5	107.2
22	....	155.8	1.54	137.3	.64	91.2	1.50	74.2	1.55	....	1.31	114.6	104.4
23	....	81.7	1.13	119.2	.45	69.3	1.50	47.4	1.55	....	1.16	79.4	71.0

<sup>1</sup> Not run.

N. P. = Nitrifying Power, i. e. Mg. NO<sub>3</sub> formed per 100 gm. soil in 4 weeks.

NH<sub>3</sub>-N = Mg. ammonia nitrogen per 100 gm. soil.

TABLE III  
EFFECT OF CHECKING NITRIFICATION UPON THE ACCUMULATION OF AMMONIA  
NITROGEN UNDER FIELD CONDITIONS  
(Expressed in mg. per 100 gm. soil)

Plot No.	Series A		Series B	
	NH <sub>3</sub> -N	NO <sub>3</sub>	NH <sub>3</sub> -N	NO <sub>3</sub>
A	0.52	18.2	1.09	14.0
B	0.45	17.3	1.09	12.6
C	0.61	15.7	1.25	11.9
D	0.74	17.2	1.48	11.6
E	0.98	10.9	1.55	9.5
F	1.46	9.8	2.62	7.4

Treatment of plots: A—0; B—5 c.c.; C—10 c.c.; D—25 c.c.; E—50 c.c., and F—100 c.c. of CS<sub>2</sub> per sq. ft. Series B an addition of cottonseed meal.

TABLE IV  
COMPARISON BETWEEN AMMONIA NITROGEN CONTENT OF SOILS AND YIELD  
FROM DIFFERENT PLOTS, ROTHAMSTED STATION

Date	Hoos Field Barley Plots					Broadbalk Wheat Plots	
	7-2	1-0	1A	2A	4A	7	10
4-8	7.0	1.6	4.3	....	13.0	12.9	18.6
5-7	4.0	...	1.6	1.6	2.0	2.6	15.0
6-11	4.0	1.0	1.6	1.6	1.6	2.2	2.2
7-12	5.3	1.0	1.6	1.0	2.2	1.6	4.3
10-28	4.0	0.5	1.0	1.0	1.0	1.6	2.2
Yield '09.....	46.3	13.0	21.3	29.2	44.3	28.9	19.5
Yield '60-yr.....	47.1	12.7	25.5	38.2	41.5	32.1	20.0

Note:—Plots 1A, 2A, 4A, 7 and 10 have received an application of ammonium salts. For 1909, Plots 1A, 2A and 4A received an addition on February 20-21. Plots 7 and 10 received an addition on April 7, the day before the first analysis was made. Plot 7-2 has received an annual application of dung. Plot 1-0 has received no application.

Russell gives data for Plot 7-0, but since no plot corresponding to such could be located in Rothamsted Guide and 7-2 does correspond to the one reported by Russell, we presume the 0 to be a typographical error.



TABLE V  
RELATION BETWEEN AMMONIA-NITROGEN CONTENT AND YIELD, PENNSYLVANIA AGRICULTURAL EXPERIMENT STATION

Plot No.	NH <sub>3</sub> -N Per cent	Wheat bu.	Corn lbs.	Oats bu.
21	.00120	27.5	4,240	52.3
24	.00105	11.5	1,080	39.0
28	.00100	34.2	4,720	59.2
32	.00100	12.7	1,408	50.2

Treatment of plots: No. 24—nothing; others, 100 lbs. K<sub>2</sub>O and 48 lbs. P<sub>2</sub>O<sub>5</sub>, and in addition: No. 21—72 lbs. nitrogen as dried blood; No. 28—72 lbs. nitrogen as NaNO<sub>3</sub>; No. 32—72 lbs. nitrogen as (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>.

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## ARE ALL THE SOIL BACTERIA AND STREPTOTHRICES THAT DEVELOP ON DEXTROSE AGAR AZOFIERS?<sup>1</sup>

By

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It has been noticed many times that there are a large number of organisms other than *Azotobacter* which develop on nitrogen-free dextrose agar plates, when these plates are made directly from a soil suspension. Apparently, no one has made any attempt to determine the nature of these organisms, and the questions arise: Are they all azofiers or nitrogen fixers, and if so, to what class do they belong? If they are not azofiers, where do they get their supply of nitrogen?

In order to answer these questions, the following experiment was carried out. One hundred gm. of soil<sup>2</sup> were placed in 200 c.c. of sterile water, thoroughly shaken for 5 minutes, dilutions of 1 to 1000, 1 to 10,000 and 1 to 20,000 made, and 12 dextrose agar plates prepared by the usual method. The following modification of the mannite medium recommended by J. G. Lipman (3) was used:

Distilled water .....	1000 c.c.
Agar agar .....	12 gm.
Dextrose .....	15 gm.
K <sub>2</sub> HPO <sub>4</sub> .....	0.2 gm.
MgSO <sub>4</sub> .....	0.2 gm.
CaCl <sub>2</sub> .....	0.02 gm.
10% Fe <sub>2</sub> Cl <sub>3</sub> solution.....	1 drop.

The solution was made neutral to phenolphthalein by the use of 10 per cent NaOH before the addition of the agar. The plates were incubated for 4 days at room temperature, the colonies counted and the plate that contained approximately the correct average number of colonies was set aside for further study. The count showed that the soil contained per gram of dry soil, 2,400,000 bacteria that were able to develop on nitrogen-free medium.

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<sup>1</sup> Received for publication January 13, 1917.

<sup>2</sup> Miami silt loam.

The area of the selected plate was then divided into 4 equal parts, each part containing the same number of colonies. Each of these areas was considered to contain a fair representation of all the bacteria in the original soil that were able to develop on this medium. All the bacterial colonies in one of these areas were picked out and transferred to slants of the same medium. In this manner 30 colonies were separated, replated to insure their purity and their azofying power determined both in soils and in solutions. In the purification of these organisms it was found that 3 colonies developed two distinct organisms. These were isolated and purified and their azofying power determined with the others. The total number of organisms studied was therefore thirty-three.

No attempt was made to classify these organisms further than to divide them roughly into 4 groups, each having distinct cultural characteristics that were easily recognized. The grouping and the number of organisms in each group were as follows:

Group 1-- <i>Nocardia</i> "Actinomyces" .....	10 colonies.
Group 2--Small jelly-like colonies resembling <i>Bacillus radiclecola</i> .....	10 colonies.
Group 3--Flat, thin, fluorescent colonies .....	7 colonies.
Group 4--Thick, dense, white shiny colonies, opalescent, raised in center and growing somewhat in concentric rings .....	6 colonies.

The soil medium for the azofication tests was prepared as follows. One hundred gm. of air-dried sieved soil of the same type as that from which the organisms had been isolated were placed in tumblers, covered with a thick layer of cotton securely fastened with a cord, and sterilized in the autoclave for 4 hours at 15 pounds pressure. The sterilization was repeated 3 times, 1 day being allowed to elapse between operations. Thorough sterilization of the soil was proven by careful plate tests.

The solution used in the azofication tests was the same as that employed in the isolation work, except that 10 gm. of dextrose were used instead of 15. Fifty c.c. of this solution were placed in flasks and sterilized in the usual manner.

The inoculum was prepared by inoculating the organism into tubes containing 5 c.c. of the above solution. After incubating 3 days, sufficient growth appeared to insure good inoculation which was accomplished by flaming the ends of the tubes and the plugs, and pouring the entire contents of the tube into the medium to be inoculated. This operation took place under an inoculating hood in order to avoid any contamination. In the case of the soil tests no dextrose was added other than that in the 5 c.c. of inoculum, it being assumed that the complete sterilization by heat had rendered soluble sufficient nutrient to make the addition of any carbon supply unnecessary; however, sufficient sterile water to make the content up to the optimum, 22 per cent, was added immediately after the addition of

TABLE 1  
DETERMINATION OF NITROGEN FIXATION

## NOCARDIA

Lab. No.	Solution			Soil				
	Mg. N Found	Blank	Mg. N Fixed	Mg. N Found	Duplicate Mg. N Found	Average Mg. N	Check Mg. N	Mg. N Fixed
1	2.66	0.56	2.10	309.4	315.0	312.2	298.2	14.0
3	5.74	0.56	5.18	316.4	319.2	317.8	298.2	19.6
4	3.22	0.56	2.66	313.6	308.0	310.8	298.2	12.6
8	.....	.....	Lost	298.7	303.8	301.2	298.2	3.0
8X	7.56	0.56	7.00	.....	.....	.....	.....	Lost
9	3.64	0.56	3.08	316.4	310.8	313.6	298.2	15.4
10	0.42	0.56	0.00	322.0	322.7	322.3	298.2	24.1
13	4.62	0.56	4.06	309.4	306.6	308.0	298.2	9.8
26	2.66	0.56	2.10	318.5	315.7	317.1	298.2	18.9
27	2.24	0.56	1.68	312.9	323.4	318.1	298.2	19.9

## RADICICOLA-LIKE FORMS

2	3.92	0.56	3.36	310.8	315.7	313.2	298.2	15.0
11	1.12	0.56	0.56	311.5	312.7	312.1	298.2	13.9
12	1.26	0.56	0.70	314.3	312.7	313.5	298.2	15.3
17	0.42	0.56	0.00	285.6	294.7	290.1	298.2	0.0
20	2.10	0.56	1.54	309.4	310.8	310.1	298.2	11.9
21	1.82	0.56	1.26	317.8	317.8	317.8	298.2	19.6
21X	0.98	0.56	0.42	320.6	322.0	321.3	298.2	23.1
28X	1.12	0.56	0.56	316.4	315.0	315.7	298.2	17.5
22	0.56	0.56	0.00	312.9	303.8	308.3	298.2	10.1
30	1.26	0.56	0.70	305.2	309.4	307.3	298.2	9.1

## FLUORESCENT

15	4.34	0.56	3.78	305.2	306.6	305.9	298.2	7.7
16	0.84	0.56	0.28	303.1	308.0	305.6	298.2	7.4
19	0.98	0.56	0.42	307.3	310.1	308.7	298.2	10.5
23	0.00	0.56	0.00	317.8	319.2	318.5	298.2	20.3
24	0.98	0.56	0.42	311.5	312.9	312.2	298.2	14.0
25	1.26	0.56	0.70	315.0	305.2	310.1	298.2	11.9
28	3.64	0.56	3.08	322.7	324.1	323.4	298.2	25.2

## OPALESCENT

5	2.66	0.56	2.10	319.2	317.8	318.5	298.2	20.3
6	0.98	0.56	0.42	317.8	326.2	322.0	298.2	23.8
7	1.12	0.56	0.56	302.4	302.4	302.4	298.2	4.2
14	5.18	0.56	4.62	310.8	318.5	314.7	298.2	16.5
18	1.26	0.56	0.70	310.1	314.3	312.2	298.2	14.0
29	5.88	0.56	5.32	304.3	308.0	306.1	298.2	7.9

the inoculum. This optimum water content was maintained during the incubation period by bringing it up to weight at regular intervals with sterile water. The soils and the solutions were all incubated for 3 weeks at room temperature, and the nitrogen content determined at the end of that period by Kjeldahling. The only variation in the determination from the regular routine of the Kjeldahl determination was that instead of distilling, the digested material was aerated following the Potter and Snyder (4) modification of the method suggested by Kober and Graves (2). Tables I and II show the results of these determinations.

TABLE II  
SUMMARY OF TABLE I

	Average Mg. N Fixed	
	Solution	Soils
Nocardia .....	3.095	15.255
Radicicola-like forms .....	0.910	13.550
Fluorescent .....	1.240	13.855
Opalescent .....	2.286	14.450

It was surprising to find the organisms in the *Nocardia* group developing so abundantly on this medium, but Table II shows that not only are they azofiers, but that they are able to fix on the average a higher amount of nitrogen than the other soil organisms. So little work has been done on this group of organisms by soil investigators that the author was unable to find any definite data on their azofying power. Beijerinck (1) worked with one member of the group, *Streptothrix chromogena*, and came to the conclusion that it was not able to fix atmospheric nitrogen but that it lived on the small amount of nitrogen contained in the medium. A number of investigators have shown the large percentage of these organisms in the soil, and a few have studied their activities. This point is fully discussed in another paper. These results indicate that this group of soil organisms may be quite important in increasing the nitrogen content of soils.

It will be noticed that there is but one organism, No. 17, that did not fix any nitrogen in either soil or solution, and only four, Nos. 10, 17, 22 and 23, that did not fix any in solution. Of these four, three fixed appreciable amounts in the soil. It may be assumed, therefore, that in the light of the above results, 97 per cent of these soil organisms developing on dextrose agar plates were azofying bacteria. What they are, and what their activities are, compared with the known activities of the *Azotobacter* and the *Radicicola* groups, are questions that should be of great importance to the soil bacteriologist. The results become of greater interest when it is realized that no *Azotobacter* were present, showing clearly that there are a large number of organisms in the soil other than

*Azotobacter* and *Radicala* which have the power of fixing atmospheric nitrogen. Apparently, nothing is known at present of the activities of these organisms, but is it not possible that their presence would explain the nitrogen increase usually observed in fallow soils? Numerous instances are on record where authors have reported large bacterial counts on nitrogen-free media, showing that the distribution of these or similar organisms is quite general. It appears, therefore, in the light of the above investigations that if general farming practices favorable to the development of these organisms were followed, the problem of keeping up the nitrogen content of cultivated soils might be much simplified. The importance of further study along this line is apparent.

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STUDIES ON SOIL COLLOIDS:  
II. INFLUENCE OF COLLOIDS ON ELECTRICAL  
CONDUCTIVITY OF SALTS<sup>1</sup>

By

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When an electrical current is passed through a colloidal solution, the solid particles begin to collect at either the cathode or the anode. According to such behavior, colloids are classified as positive and negative, respectively. The observation of this and similar phenomena in the studied hydrosols led to the general belief among certain physical chemists that the colloidal particles do conduct the electrical current. This contention was held undisputed until about 10 to 12 years ago, when indirect evidence obtained by a number of investigators, working independently and on different problems, showed that colloids do not conduct the electrical current, at least to a measurable degree, and that the migration of colloidal particles is wholly due to the ions of electrolytes associated with them.

Dumanski (2) has observed that some colloids effect electrolytes differently. Strongly coagulating electrolytes show a somewhat greater conductivity in the presence of hydrosol, while the non-coagulating electrolytes show considerably less conductivity than the normal. Evidently, the difference in the adsorptive power of the colloids investigated by him accounted for such differences in the conductivity. From this indirect evidence he concluded that the colloidal particles are non-conductors of the electrical current.

Mayer and Salles (7) studied the electrical migration of colloidal arsenic sulfide and state as a result of their investigation that "the rate of motion of the meniscus at the negative end of the moving sulfide was greater than that at the positive, and that the former rate fell off, while the latter increased, during the migration." When they reversed the electrical current, an entirely opposite effect was observed. The phenomena led them to conclude that the migration depends on the ions adsorbed by the colloidal particles, and the charge of a particle depends on the number of ions adsorbed. The confirmation of their view they found in one of their experiments, in which a small amount of salt was introduced into the colloidal solution, resulting in the exaggeration of the migration phenomenon.

Bilts and von Vegesack (1), in their studies of osmotic pressure of hydrosols, came to the conclusion that the osmotic pressure of colloidal

<sup>1</sup>The results are taken from the author's thesis presented to the faculty of Michigan Agricultural College in partial fulfillment of the requirements for the degree of Master of Science.

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solutions is due to the ions of electrolytes, which are united with the colloidal particles.

Frei (5) obtained more direct evidence bearing on the question, namely, that organic colloids, such as serum albumen, globulin, gelatin and saponin, when added to sodium hydroxide, diminish the electrical conductivity of the latter. He also noticed that on diluting the colloidal solution, the increase in conductivity was faster than the rate of dilution, which he attributed, and rightly so, to the relatively greater increase of ion concentration in the liquid between the colloidal particles and the decrease of inner friction.

Richter (8) later confirmed Frei's results with organic colloids and, moreover, found that the addition of colloids causes the lowering of the transference numbers, the effect increasing with the concentration of the colloid.

Of course, both Frei's and Richter's methods of determining the influence of colloids on electrolytes are open to criticism in so far as they do not show whether the colloids hinder the movement of the ions of salts, or whether decrease of conductivity of the salt solution is due to the adsorption of free ions, causing them to be but comparatively active.

#### EXPERIMENTAL

The results of certain of the experiments herein recorded throw additional light upon the question of influence of colloidal particles on the electrical conductivity of salt solutions. Since the study was made with soil colloidal solutions obtained from clay nearly devoid of organic matter, the results add to our knowledge of the behavior of the *inorganic* colloidal solution.

#### *Method of Experiments*

The soil colloidal solution was prepared by adding to a fresh clay soil (locally known as "brick yard clay") 5 times its volume of distilled water, shaking occasionally during the day and allowing to stand over night. On the following morning the turbid solution was decanted off and centrifuged at the rate of 2000 revolutions per minute for 15 minutes. The resulting solution contained as much as 0.3633 gm. of dry weight of solid material per 100 c.c. of the solution, and remained in suspension without much sedimentation for several weeks.

To 200-c.c. portions of this solution in bottles were added different amounts of electrolytes in such proportions that the smallest amount added was not enough for complete coagulation of the colloids used, while in the case of the largest amount added, there was an excess of electrolyte. The strength of the solution was N/5 with the exception of  $\text{Ca}(\text{OH})_2$ , this being saturated. After adding the salt solution to the colloidal solution, the mixture was vigorously shaken and allowed to stand for at least 2 hours, when the solution was shaken again and emptied into thoroughly cleaned centrifuging tubes. They were centrifuged for 15

minutes, the solution was carefully decanted, and the electrical resistance of the diluted precipitate determined. All determinations were made at 25° C. The electrolytes used were aluminum potassium sulfate, ferric sulfate, lead nitrate, hydrochloric acid, and calcium hydroxide. Table I gives the average resistance of the diluted precipitates, while in the case of alum and ferric sulfate the resistance of the clarified solution was also taken.

TABLE I  
RESISTANCE OF DILUTED COLLOIDAL PRECIPITATES OBTAINED WITH  
DIFFERENT ELECTROLYTES

Amount of N/5 electrol.	AlK(SO <sub>4</sub> ) <sub>3</sub>		Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>		Pb(NO <sub>3</sub> ) <sub>2</sub>	HCl	Ca(OH) <sub>2</sub>
	Precipitate	Solution	Precipitate	Solution	Precipitate	Precipitate	Precipitate
0.1 c.c. ....	49,800	9,419	51,755	9,883	54,140	52,064	.....
0.2 c.c. ....	52,210	8,718	52,700	8,655	54,130	56,165	.....
0.3 c.c. ....	53,555	7,678	60,105	7,868	53,127	58,805	.....
0.5 c.c. ....	62,485	6,183	72,725	6,861	51,570	70,415	60,580
1.0 c.c. ....	173,175	4,599	172,450	5,595	156,270	101,230	59,835
2.0 c.c. ....	56,010	2,866	45,785	3,394	60,790	88,420	52,855
4.0 c.c. ....	40,115	1,749	27,785	2,025	51,100	62,980	40,390
8.0 c.c. ....	28,150	1,072	18,363	1,026	40,785	24,870	131,570
12.0 c.c. ....	.....	.....	.....	.....	.....	.....	29,855
16.0 c.c. ....	.....	.....	.....	.....	.....	.....	27,770
20.0 c.c. ....	.....	.....	.....	.....	.....	.....	25,472
Distilled water	54,220	.....	55,650	.....	54,220	54,210	60,100

<sup>1</sup> At this point the coagulation was complete, as well as with the larger amounts of electrolytes.

The above figures and the graphs in figure 1 show several very interesting features. First of all, one notices that with one exception with the increase of electrolyte added the resistance of the resultant precipitates (after diluting) increased up to a certain point and then began gradually to decrease, while the resistance of clear solutions, containing only electrolytes, decreased constantly on concentration. The highest resistance of 4 out of 5 electrolytes used was greater than that of the distilled water used. Besides, one observes that the highest electrical resistance occurred around the point where there were just enough electrolytes present for the complete coagulation of the clay colloidal solution. Calcium hydroxide was an exception to this rule. The discrepancy in the case of the Pb(NO<sub>3</sub>)<sub>2</sub>, however, was so small that it might be attributed to experimental error.

The results, then, tend to point out that the clay colloidal particles considerably hinder the electrical conductivity (which is inversely proportional to the resistance) of the electrolytes, and this interference is greatest at the point of complete coagulation. Two, and in some cases three, independent coagulations were made, and in each case a number of readings were taken. In general, the results are the same, namely, at a certain point the resistance of the diluted gel is greater than that of the distilled water used. Now, when the diluted precipitate obtained by adding 1 c.c. of Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub> to 200 c.c. of clay solution, which gave the resistance of 72,450 ohms (Table I), was centrifuged once more for 15 minutes, the clear solution decanted off and its resistance determined, it read 55,940

ohms as against 72,450 with the solid particles in it, and against 55,630 ohms for the distilled water used. Although these figures are considerably in favor of the contention that the inorganic colloidal gel interferes with the electrical conductivity of the solution, it seemed advisable to verify the point further. For this purpose the following experiment was performed.

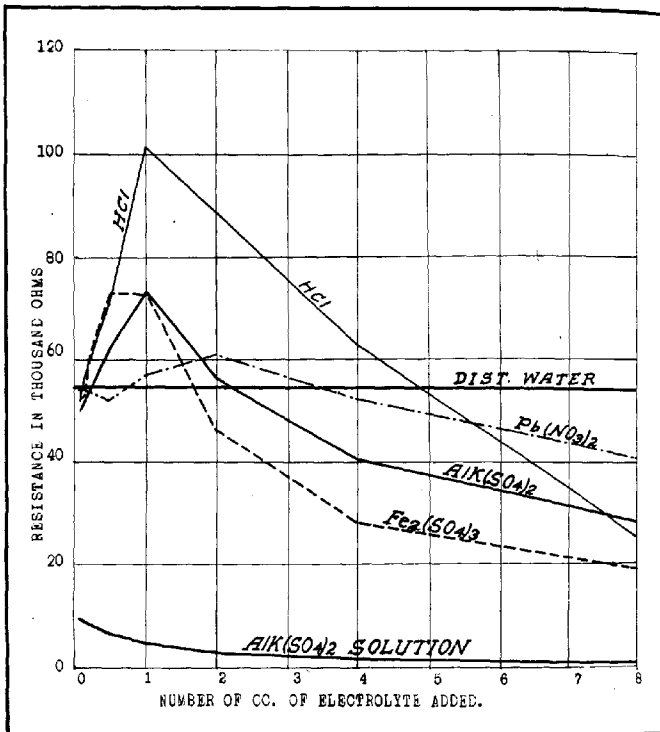


Fig. 1.—Resistance of diluted colloidal precipitates obtained with different electrolytes.

Two hundred c.c. of clay colloidal solution was flocculated with 10 c.c. of alum. The gel was separated from solution by means of the centrifuge and decanted. Then it was washed out of the tube, diluted to 200 c.c. and the electrical resistance of both the diluted gel and the clear decanted solution was determined. After the determinations were made the diluted gel was again centrifuged, separated from the clear solution and the resistance determined as in the preceding case. This was repeated several times and the results are presented in the Table II, and illustrated in figure 2.

On examining the figures in Table II it will be noticed that the resistance of the diluted gel is always greater than that of the next clear

solution, which, of course, is the same solution minus the solid particles. Consequently, the assumption regarding the interference of the colloidal gel with the conductivity of the electrolytes is correct.

The question may arise at this point, just how do these particles hinder the electrical conductivity of the free ions of the electrolytes? Two agencies could account for it. First, the colloidal particles, being much larger than the molecules or the ions of the salts, conduct electricity very slightly, if at all. When present in abundance, as in the case with our clay colloidal solution, they stay in the pathway of the ions like slowly moving travelers on a crowded sidewalk. Let them all move in the same direction, and yet the speed of the most lively ones will always be retarded by the more slow individuals. Second, there is a possibility of adsorption playing a part in bringing about the phenomenon. Referring again to Table I, one observes that an abrupt change in resistance takes place at or around the first complete coagulation. It is very possible that on coagulation, with the entire change in structure of the particles, there takes place a change in the adsorptive capacity of the colloid in question.

TABLE II  
ELECTRICAL RESISTANCE (IN OHMS) OF ALUMINUM POTASSIUM SULFATE  
SOLUTION AT DIFFERENT CONCENTRATIONS WITH AND  
WITHOUT COLLOIDAL PARTICLES

Dis- tilled H <sub>2</sub> O	First Precipitate		Second Precipitate		Third Precipitate		Fourth Precipitate		Fifth Precipitate		Sixth Precipitate	
	Decanted clear solution	Diluted gel	Decanted clear solution	Diluted gel	Decanted clear solution	Diluted gel	Decanted clear solution	Diluted gel	Decanted clear solution	Diluted gel	Decanted clear solution	Diluted gel
49,668	634	10,054	9,842	37,085	33,349	42,437	38,180	54,293	.....	.....	.....	.....
47,445	628	9,202	8,039	23,851	18,561	29,410	23,115	36,210	31,370	54,370	40,975	36,009

Though the total surface of the solid material is decreased on coagulation, yet the structure of the gel may cause the increase of the adsorptive capacity of the colloids and, therefore, may result in the decrease of the number of free ions present in solution. It is quite possible that both of the suggested agencies are at work and supplement one another.

Outside of the theoretical consideration, which was the main object here pursued, the results presented in this paper have very interesting and significant value to every investigator in any field of work dealing with colloidal solutions. If the results are true, and we have no reason to suppose them to be otherwise, they caution anyone from using the electrical bridge for determining the absolute concentration of solutions containing an appreciable amount of colloidal particles in them, such as soil solution, cell sap, solutions with a great number of microorganisms, etc.

There is another point of considerable interest and importance that is brought out by the results just presented. Referring once more to Tables I and II, one will notice that on the separation of colloids from crystalloids, or from the true solution, by coagulation, centrifuging and decan-

tation, the clear solutions approach the distilled water in their electrical resistance. For instance, the solution taken from Table I which was obtained by adding 1 c.c. of N/5 ferric sulfate to 200 c.c. of clay colloidal solution, and which gave a resistance of 72,450 ohms, when clarified by centrifuging showed practically the same resistance as the distilled water used. Again, the solution obtained on the sixth washing of the gel pre-

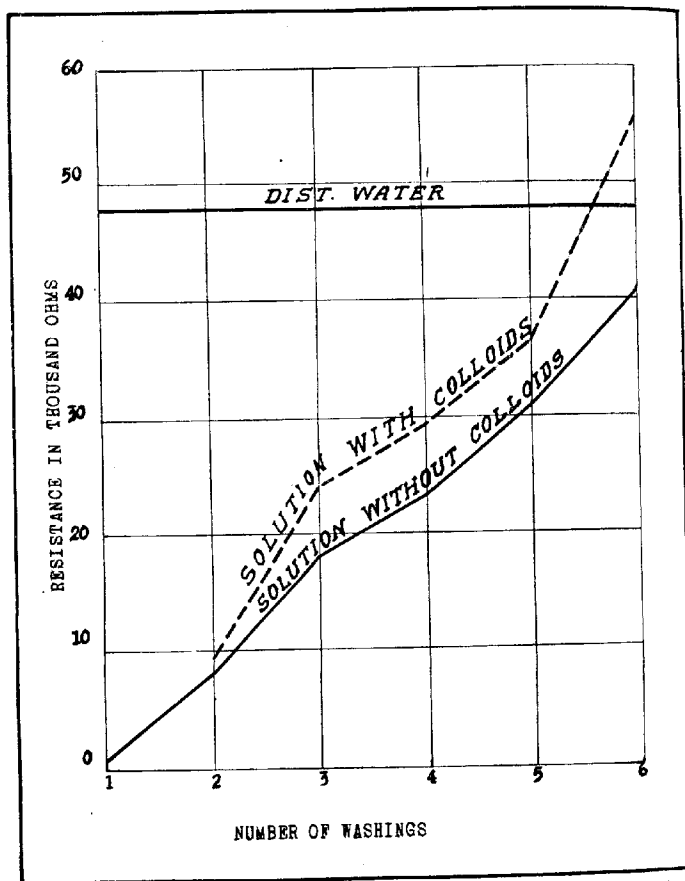


Fig. 2.—Effect of colloidal particles on the electrical conductivity of salt solution.

sented in Table II showed a resistance of 40,975 ohms as against 47,445 ohms of the distilled water. It is true that the distilled water was not of the highest purity, but for all practical purposes the purification of soil colloids to such a degree is quite sufficient. In this connection it seemed advisable to determine just to what extent the amount of electrolyte added is adsorbed by the gel, and would introduce errors in the determination of the gels.

With this object in view, the following experiment was performed. To 200-c.c. portions of clay colloidal solution were added different amounts of electrolytes, the smallest amount being just enough to cause complete coagulation of the colloids. The solutions were allowed to stand until solid particles settled, when they were centrifuged, the clear solutions were carefully decanted, and the dry weights of the gel determined. Several salts, an acid, and a base were tried, the results being summarized in Table III.

TABLE III  
DRY WEIGHT (IN GRAMS) OF GEL OBTAINED BY COAGULATING CLAY COLLOIDAL SOLUTIONS WITH DIFFERENT AMOUNTS OF ELECTROLYTES

Amount N/5 elec- trolyte added c.c.	$\text{Fe}_2(\text{SO}_4)_3$		$\text{Pb}(\text{NO}_3)_2$		$\text{Alk}(\text{SO}_4)_2$		$\text{HCl}$		$\text{Ca}(\text{OH})_2$	
	1	2	1	2	1	2	1	2	1	2
1	.0966	.0980	.0955	.0950	.0930	.0925	.0923	.0923	.....	.....
2	.1027	.1043	.0967	.0958	.0922	.0912	.0925	.0920	.....	.....
4	.1093	.1112	.0978	.0980	.0940	.0970	.0925	.0925	.....	.....
8	.1192	.1165	.1030	.0992	.0958	.0975	.1043	.1042	.0820	.0950
16	.....	.....	.....	.....	.....	.....	.....	.....	.1028	.0983
24	.....	.....	.....	.....	.....	.....	.....	.....	.1112	.0983
32	.....	.....	.....	.....	.....	.....	.....	.....	.1138	.0997

200 c.c. of original solution was evaporated to dryness, giving .1015 gm. residue.

Making due allowance for experimental error, the results show a remarkably close agreement in the dry weight of the gels obtained at or around the point of complete coagulation with the minimum amount of an electrolyte present. On further addition of an electrolyte the dry weight of the gel gradually increased until it exceeded the dry weight of the original solution. This increase in weight was naturally expected and undoubtedly is due to the increase in adsorption of the ions of the electrolytes. The adsorption of different ions is not the same, and is the smallest in the cases of aluminum potassium sulfate and hydrochloric acid, followed by lead nitrate and calcium hydroxide, and, finally, by ferric sulfate. The salts here used are of the best coagulants selected from some 70 electrolytes studied by the author (9). The solution obtained by these means is perfectly clear to the naked eye and is absolutely homogeneous under the microscope. The resultant gel, of course, is not entirely free from electrolytes, but the error on this account is very small and surely is much smaller than when an abundance of common salt is used, as recommended by Hilgard (6), or when ammonium carbonate is employed, which is advised by Dupont (3) and again by Fraps (4). Both of these electrolytes are comparatively poor coagulants, as was previously reported (9), and it requires a large amount of these salts to bring about complete coagulation, especially, when the colloids are largely of organic origin. In the presence of these facts, the method here outlined is recommended for the separation of soil colloids from crystalloids in determining the colloidalilty of soils.



## SUMMARY

1. The inorganic colloidal particles, as found in clay, especially the colloidal gels, hinder the electrical conductivity of salt solutions.
2. The causes for such an interference lie possibly in (a) the fact that colloidal particles moving comparatively slowly are in the pathway of the free ions, and (b) that the change of the structure of the gel at the point of coagulation results in an increase in the adsorptive capacity of colloids.
3. The adsorption of electrolytes by the gel increases with the increase of the electrolyte present for coagulation.
4. The coagulation of the colloidal solutions by means of certain electrolytes can be employed for separation of colloids from crystalloids, provided that only a minimum amount of electrolyte be used for a complete coagulation in order to reduce to the minimum the error due to adsorption.

## ACKNOWLEDGMENT

The author wishes to express his gratitude to Dr. M. M. McCool for many valuable suggestions during the work and for critically reading the manuscript.

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# THE MONONCHS<sup>1</sup>

(*Mononchus* Bastian 1866)

## A GENUS OF FREE-LIVING PREDATORY NEMATODES

CONTRIBUTIONS TO A SCIENCE OF NEMATOLÓGY VI

(With 75 illustrations in the text)<sup>2</sup>

By

N. A. COBB, *United States Department of Agriculture*

### INTRODUCTION

#### *Mononchs are Predaceous*

No free-living nematodes have gained more in interest during recent years than those constituting the genus *Mononchus*; this is because the latest discoveries have led to a complete change of view concerning their economic relationships. Careful examination, here recorded, of a large number of specimens belonging to many different species of *Mononchus*, has fully demonstrated the predaceous character of certain common and widely spread soil-inhabiting species—which are found to feed on other small animal organisms, such as protozoa and rotifers, and, most interest-

<sup>1</sup> Received for publication February 3, 1917.

<sup>2</sup> For the most part the illustrations were prepared under the author's personal supervision by Mr. W. E. Chambers of the Bureau of Plant Industry. Many features set forth in them cannot be seen in the natural object except with the aid of the best immersion lenses skillfully used under favorable conditions. Frequently no further allusion is made to facts thus elucidated. So, too, information contained in the key may not be repeated elsewhere; the key should therefore be consulted in connection with each description. Most of the illustrations are original; when not so, their source is indicated. The species figures are all at the same magnification, so that the reader may judge of the relative sizes of the nemas. Explanatory abbreviations follow.

amp—ampulla	lb—lips	ov im—immature egg
amph—amphid	lum int—lumen of intestine	p ex—excretory pore
an—anus	lum oe—lumen of œsophagus	ph str—pharyngeal striæ
an gl—anal gland	lum som—body cavity	por—pore
ar dnt—denticular area or rasp	ms an—anal muscle	por gl oe—pore of œsophageal gland
cav som—body cavity	msc oe—œsophageal muscle	ppl—papilla
cl int—intestinal cell	msc som—body muscle	ppl cdl—caudal papilla
cl msc—muscle cell	mur int—intestinal wall	ppl intr—interior papilla
cl nrv—nerve cell	mur ph—pharyngeal wall	ppl lb—labial papilla
cl nrv subm—submedian nerve cell	mur ut—wall of uterus	ppl lb extr—exterior labial papilla
col crd—cardiac collum	ncl—nucleus	
crd—cardia	ncl cl int—nucleus of intestinal cell	
est ph—pharyngeal rib	ncl lat—lateral nucleus	
cut—cuticle	ncl ov—nucleus of ovum	
det—duct	nrv—nerve	
det gl cdl—duct of one of the caudal glands	nrv r—nervur ring	
dnt—denticules	oe—œsophagus	
flx ovr post—flexure of posterior ovary	oes lum—œsophageal lumen	
gl—gland	on dsl—dorsal tooth	
gl an—anal gland	on rtr dsl—retrorse dorsal tooth	
gl cdl—caudal gland	on rtr subm—retrorse submedian tooth	
gl oe—œsophageal gland	on subm dxt—right submedian tooth	
gl sal—salivary gland	on subm snst—left submedian tooth	
ing—ingested material	org—organ	
ing nematod—ingested nematode	ov—ovum	
int—intestine	ov dcl—oviduct	
inc—incision	ov frt—fertilized egg	
lum lb—labial lamina		
		ov im—immature egg
		p ex—excretory pore
		ph str—pharyngeal striæ
		por—pore
		por gl oe—pore of œsophageal gland
		ppl—papilla
		ppl cdl—caudal papilla
		ppl intr—interior papilla
		ppl lb—labial papilla
		ppl lb extr—exterior labial papilla
		ppl subm—submedian papilla
		ppl subm sec—secondary submedian papilla
		ppl trm—terminal papilla
		rcpt sem—seminal receptacle
		rct—rectum
		reg vnt—ventral field
		set—seta
		spm—spermatozoa
		spn—spinneret
		str mur ph—striae of pharyngeal wall
		subcut—subcuticle
		sut lb—labial suture
		teg ov—egg shell
		trm ovr—blind end of ovary
		ut—uterus
		vag—vagina
		vag msc—vaginal muscle
		viv—vulva

ing of all, on other nemas—and has made it practically certain that all mononchs are predaceous.

*Economic Importance.* If, as is often the case, the nemas destroyed by the mononchs are nemas injurious to agriculture, then the mononchs are beneficial to man. The first definite instance of this kind was reported in the *Journal of Agricultural Research* in September, 1914: *Mononchus papillatus* was shown to feed upon *Tylenchulus semipenetrans*, the latter a nema infesting the roots of citrus trees. Since that time the writer has observed many similar instances, fourteen of which are recorded herein.

Formerly mononchs were considered harmful to vegetation. The basis of this opinion was twofold: first, they were known to congregate about the roots and between the leaf sheaths of plants, especially succulent plants, in sufficient number to justify the opinion that they would be harmful, provided they were vegetarians; second, vegetable matter was often found in their intestines.

More careful investigation, however, has disclosed other facts incompatible with this opinion that mononchs are harmful to vegetation. The food-habits of mononchs have now been more carefully investigated, as herein recorded, and each species so studied has proved to be carnivorous. The presence of vegetable matter in a mononch's intestine proves to be no very definite criterion of its food habits, appearances to the contrary notwithstanding.

A deception has arisen that is now easily explained. The occurrence of vegetable organisms in the intestine of a mononch is merely incidental; in many instances it would be impossible for the mononch to devour its prey without at the same time swallowing vegetable matter. For instance, suppose a mononch to bolt, as one of its victims, a monhystra—a common occurrence. Monhystras are vegetarians, some of them feeding almost exclusively upon diatoms, others upon other kinds of unicellular algæ. Both on account of their peculiar structure and their bright green color, these diatoms and other algæ are very conspicuous objects in the intestine of the monhystra. Imagine now the appearances presented by the body of an ingested monhystra, swallowed whole, or nearly so, and

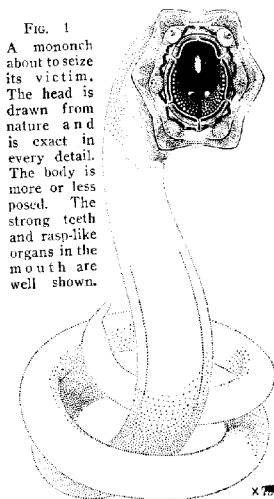


FIG. 1  
A mononch about to seize its victim. The head is drawn from nature and is exact in every detail. The body is more or less posed. The strong teeth and rasp-like organs in the mouth are well shown.

lying lengthwise in the intestine of a mononch. Under such circumstances, which are entirely normal, the diatoms and other algæ in the intestine of the monhystra may be observed through the colorless tissues

of both the mononch and the monhystera, without the body wall of either nema being very plainly visible: it is somewhat as if one looked through the walls of two glass tubes, one within the other, to view comparatively conspicuous objects in the inner tube. Such an observation might easily lead to the conclusion that the mononch had been feeding upon unicellular algæ. The deception is heightened after the body of the monhystera is partially digested, for then all vestiges of the monhystera become practically invisible, and there are left as comparatively conspicuous remains the less readily digested vegetable matter, lying loose in the intestine of the mononch,—the frustules of diatoms for instance, which of course are wholly indigestible. Taking everything into consideration, it is not in the least surprising that hitherto observers have been deceived as to the food habits of mononchs.

As nematologists heretofore have not carefully studied the food habits of mononchs, particular attention was given them in the course of these investigations; but in spite of the care exercised much remains to be discovered. The mouth parts and digestive organs have come in for special study, since it is mainly here that we get clues, faint and puzzling though they be, that help interpret the little we can glimpse of the food habits of these organisms in their natural state. Soil mononchs live in darkness and, as might be expected, behave in a wholly unnatural way when placed in water on a microscope slide and brought in a drowning condition into the blaze of light necessary to a microscopic examination. The difficulties and delays attendant on such a line of research are manifest. Nevertheless, certain fundamental facts have been established; new organs have been discovered and light has been thrown on the true nature and function of organs not hitherto understood. It has seemed best to dwell on the various habits and functions while describing the structures with which they are associated.

As we gain familiarity with the food habits of nemas, it becomes possible on this new basis to make comparative anatomical studies, the results of which may be applied in determining the food habits of newly discovered genera and species.

## I

### STRUCTURE, FUNCTIONS, AND DISTRIBUTION OF MONONCHS

The mononchs constitute a genus of free-living, predatory nematodes inhabiting soil and fresh water, as well as the above-ground parts of certain plants. The average form and size of a mononch is indicated by the following average formula:

2.2	7.4	25.	*63 <sup>mm</sup>	92.7	
2.1	2.6	3.	3.2	2.	2.4 mm.*

\* This formula, which is now coming into more general use, is simply a decimal method of stating concisely the necessary measurements. The formula is fully explained in the appendix, p. 486.



resolve the striæ into components; occasionally, however, they are resolvable into rows of excessively fine dot-like elements, as for instance in *bathybius*, *reversus* and *incurvus*. Lateral wings to the cuticle are almost unknown, and the striæ are not perceptibly altered on the lateral fields; *papillatus* and *macrostoma* furnish a slight exception to this rule.

Though the muscles of the body wall are relatively powerful, their attachments to the subcuticle are not a conspicuous feature; hence longitudinal striæ due to this cause, though of rather common occurrence, are not very readily observed. There are no longitudinal striations in the cuticle proper. This apparent complete absence of dermal markings often imparts a glassy appearance to living mononchs when examined casually under the microscope, an effect that is heightened by the fact that the colorless body wall is, as a rule, of more than average thickness. Despite their rather thick cuticle, mononchs are very flexible. They coil and uncoil themselves with facility,—a useful gift in a struggle with active prey.

*Moulting.* From researches on a considerable variety of genera, Maupas concluded that nematodes undergo four moults, and that, correspondingly, the life of each individual is divided into five periods. He examined no mononchs. The accompanying sketch of a portion of the pharynx of a moulting *Monochus brachyuris*, from Arlington, is therefore of interest, as indicating that this specimen had yet to moult three times; and since it was already half-grown (0.8 mm. long) it is fair to presume it had already moulted once, although of course there is no proof of this. The sketch shows four successive dorsal onchi, numbered in chronological order, each the representative of a separate cuticle. The fourth onchus is in a very rudimentary state. This record accords with the observations of Maupas, and indicates the probability that mononchs also moult four times.



FIG. 3.—Head of a moulting mononch, showing successive dorsal teeth, 1, 2, 3, 4.

*Strength and Activity.* Various features of the cuticle and body-muscles seem to stamp the mononchs as powerful nemas, and when they are taken from their natural haunts and placed in a glass of water for examination, their active serpentine movements fully justify the inference. Though less agile than species belonging to some other genera, they are anything but sluggish. The movements of the anterior extremity are especially striking, a certain suppleness of neck enabling them to dart the head suddenly here or there in almost any direction,—a faculty enabling them with ease to capture their prey, even though it be active.

#### *Nemas Sometimes Float*

*Distribution by flotation.* Ditlevsen notes a very interesting trait of his *Mononchus spectabilis*, namely, that of floating on the surface of water. A number of free-living nemas belonging to other genera are

known to have this faculty, which is due to repulsion between the cuticle and water; de Man found it to exist in the case of *Oncholaimus viscosus*, and the writer has observed it in the case of the larvæ of *Diplogaster aerivora*, although a second larval form of this same species does not exhibit the property, nor do the adults. Ability to float is known also of a number of other species, and, as Ditlevsen's observations show, is not absent in the genus *Mononchus*. Whether flotation plays any part in the economy of such nemas is not known with certainty. Floating on the surface of moving water, nemas would doubtless sometimes be quickly and widely distributed, and it is therefore easily conceivable that flotation has some definite bearing on the life history of species exhibiting it.

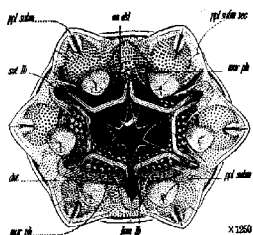


FIG. 4.—Front view of the head of *M. tenuis*. Compare with Fig. 1. Here the lips are nearly closed, but the dorsal tooth and rasps can be seen through the six labial flaps. The two circlelets of papillæ are seen to good advantage. The large dorsal tooth shows faintly through the two upper lips.

The surface of a mononch seems almost entirely destitute of setæ and papillæ, if we except those on the lips. Nevertheless, future researches will probably reveal superficial nerve-endings hitherto overlooked. In rare instances a few fairly well-developed setæ occur on the tail, as in the case of *M. signatus*; papillæ also occur sparingly on the tails of the males of various species, and near the vulva on the females of a number of species. No pores are known to occur in the cuticle, except, of course, the spinneret pore, and the pore observed near the nerve-ring and supposed to be the renette pore.

#### General Form of Body

**Neck and Head.** The various mononchs are considerably alike in external form. In front the body tapers but little; the neck is nearly always more or less cylindroid, and almost invariably ends in a head not set off from the neck in any way, though there is usually a slight expansion at the lip-region, due to the strong development of the labial papillæ.

**Tail and Spinneret.** The posterior portion of the body usually tapers from some distance in front of the anus, but in the pre-anal region the diminution is slight and very gradual. The tail may be either simply conoid, or first conoid and then cylindroid, and usually ends in a spinneret, though in about one-fourth of the species the caudal glands and spinneret are absent. When the tail is conoid the spinneret is usually a simple structure, whose existence is indicated mainly by the fact that the terminus is sub-truncate in form, and presents an inconspicuous axial, or sub-dorsal, or sub-ventral pore. This form of spinneret appears to be entirely unarmed, though inconspicuous innervations probably occur.

When the posterior portion of the tail is cylindroid, the terminus is usually almost imperceptibly expanded, and the spinneret is then somewhat differently developed, and is usually armed with obscure, innervated, submedian papillæ or setæ.

### Head

*Lips.* In the view usually obtained the six lips appear to be more or less confluent, and if it were not for their papillæ it would be difficult to count them; but when thrown apart, an attitude in which, however, they are seldom seen, they are more easily counted, since in this attitude the refractive "ceratinous" internal elements of the lips are separated from each other and more readily distinguishable, as shown in figure 1. When closed, these six, broad, flat lips meet together in such a way that the star-shaped mouth opening usually lies in a slightly depressed area on the middle of the front of the head. In some species the inner walls of the lips are strongly "ceratinized," and may be developed into six rather definite, retrorse, subacute points, which, in assaults on other animals, serve as grappling hooks, and act in opposition to the dorsal tooth of the pharynx.

*Labial papillæ.* Each lip is supplied with at least two, usually more or less conical, innervated papillæ; one on the outer margin and somewhat outward pointing, the other situated about half way between the outer papilla and the centre of the head, and forward-pointing. The front of the head therefore presents two circlets of papillæ, one on its outer margin, and one more closely surrounding the mouth-opening, as shown in figures 1 and 4, and many others. These papillæ may be so flat as to play no conspicuous part in the external conformation of the head, or they may be conical and raised, so as to give to the front of the head a more or less angular contour. The papillæ are slightly mobile, and hence vary somewhat in appearance at different times on the same specimen, a matter depending on the attitude of the lips. Drowned specimens with relaxed lips present a slightly different appearance from those that have been fixed for examination by means of chemicals.

Some of the innervations that frequently occur on the head near the lips may have special functions. Structurally they are sometimes indistinguishable from the subordinate labial papillæ. The species figures show the location of some of these innervations. One pair of them is very near the amphids—the only nerves so far observed to be definitely associated with the amphids. These particular papillæ are so uniform in their occurrence that it seems likely they have a special function, connected with the use of the amphids.

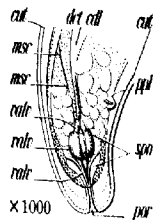


FIG. 5.—Spinneret of *M. lacustris* showing muscle, *msc*, whose contraction opens the spinneret valve.



## I

*Mononchus*: Number of Labial Papillæ in the Outer Set

14	10		6	Doubtful: said to be 6	
acutus	bathybius	muscorum var. microlaimus	brachyuris	dadayi	obtusicaudatus
brachylaimus	brevicaudatus	obliquus	lacustris	digiturus	parvus
dentatus	consimilis	radiatus	megalaimus	dolichurus	punctatus
gracilicaudatus	denticulatus	reversus	minor	exilis	rex
major	gerlachei	sigmaturus	palustris	fovearum	spectabilis
monhystera	incurvis	similis	sparsus	gymnolaimus	studerii
muscorum	longicaudatus	tenuis	teres	index	tenuicaudatus
papillatus	longicollis	trichurus	tunbridgensis	intermedius	tridentatus
rapax	micrurus	vorax		japonicus	truncatus
regius				macrostoma	zschokkei

*Comparative morphology of the cephalic papillæ.* The outer set of cephalic papillæ is the morphological equivalent of the circlet of cephalic setæ often to be seen on other free-living nemas. In harmony with this fact, the submedian papillæ of this outer set are sometimes two or three in number to each lip, the numerical and morphological factors harmonizing with the law of arrangement of the tactile cephalic setæ of nemas, namely:—when six are present one is found on each of the two lateral lines and one on each of the four submedian lines; when more than six are present the increase occurs first on the submedian lines, the commonest number being ten,—one on each lateral line and two on each of the four submedian lines; when the number is in excess of ten the increase is again more commonly found on the submedian lines. Illustrations of this law of arrangement are seen on the heads of many mononchs. The secondary submedian papillæ of mononchs are sometimes minute and more or less difficult to detect.

*Method of Hunting*

*Senses of Smell and Taste.* Obviously mononchs hunt by the aid of some other sense than that of sight, since both they and their prey usually live in subterranean darkness. It is, therefore, exceedingly likely that the nerve endings on the head, terminating in the labial papillæ of the inner row, serve as organs of taste and smell, and that it is by the aid of these senses that they trail their quarry.

Picture these ferocious little mononchs engaged in a ruthless chase in the midst of stygian darkness. We may imagine them taking up the scent of the various small animals upon which they feed, among which almost anything they can lay mouth to seems not to come amiss, and pursuing them with a relentless zeal that knows no limit but repletion. How many acres have their organic balance determined by their millions of prowling mononchs?

### Pharynx

The six powerful lips arch together over a large characteristic pharynx, consisting of a rather simple, ellipsoidal or elongated cavity, whose cross-section is more or less irregularly circular, and of which there are two distinct types.

*Types of Maw. Teeth.* In one type, characteristic of the larger species, there are longitudinal ribs, sometimes simple, sometimes duplex, situated mainly on the median and submedian lines (subgenus *Iotonchus*).<sup>3</sup> When these longitudinal ribs are well-developed there is a tendency for the dorsal tooth or onchus to be farther back, and for the submedian teeth, smaller still, to be located toward the base of the pharynx, and in extreme cases all three teeth may be located actually at the base of the pharynx, or indeed be quite vestigial. The farther back the teeth, the smaller they are, and when located actually at the base of the pharynx they are often exceedingly small.

In the other type of pharynx the dorsal tooth is usually strongly developed, and is located midway or farther forward; in which case

the wall of the pharynx is strongly reinforced along the dorsal line, while the submedian longitudinal ribs are lacking, or at any rate are faint. However, there often occurs on each of the two ventrally submedian lines in this type of pharynx an onchus of smaller size, located a little farther back than the main onchus; exceptionally these submedian onchi may be nearly as large as the dorsal onchus. In several species the onchi are retrorse (subgenus *Anatonchus*<sup>5</sup>), and when of this character are sometimes more slender, even somewhat digitate.

*Fangs. Denticles.* The onchi act as fangs, and are used in conjunction with the powerful lips in seizing and holding the prey. In these maneuvers they are aided by minor pharyngeal structures, prominent among which in some species are two submedian

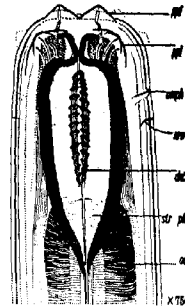


FIG. 6.—Dorsal view of the throat of *M. muscorum*, to show the arrangement of denticles (dnt.) characteristic of the subgenus *Prionchulus*.<sup>2</sup> They constitute a rude "saw." Compare with Fig. 7.

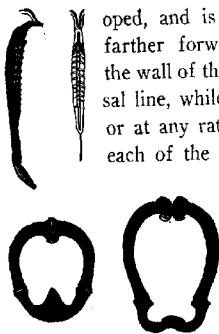


FIG. 7.—Above, profile and front view of the same series of denticles in the throat of *M. muscorum*. Below, two cross-sections of the same specimen, showing end view of the same denticles; at left the section is through the dorsal tooth (shown black); at right the section is above the tooth. The denticles are shown in the upper part of these two lower figures. The two joints shown in cross-section impart a slight degree of mobility to the pharyngeal walls. Compare with Fig. 6.

<sup>3</sup> *Iotonchus*, insignificant tooth; <sup>4</sup> *Prionchulus*, a small saw-tooth; <sup>5</sup> *Anatonchus*, reversed tooth.

areas, armed with minute denticles arranged in transverse rows like the teeth of a rasp (subgenus *Mylonchulus*<sup>a</sup>). While these denticles are usually distributed in two distinct areas, the two sometimes coalesce on the ventral line, so that the denticulated area, or rasp, is continuous and bilaterally symmetrical. As a rule, however, there is a distinct, narrow, ventral interruption, so that the right and left rasps are rather clearly separated from each other. These rasps are widest near the ventral line, and become gradually narrower as they recede, and usually end near the lateral line, or near the dorsally submedian line. On the margins of the rasps the denticles are arranged in distinct rows; elsewhere the arrangement is more or less irregular, though in certain species the arrangement is rather orderly throughout. Each rasp is composed of about six rows of denticles, except in the species *denticulatus*, where the number of rows is about twice (?) as great, and in the new species *sparsus* and *reversus*, where there are only one or two rows. Often at the base of each rasp there is an exceedingly minute submedian onchus.

*Method of Attack.* When used in conjunction with the strong dorsal tooth and the powerful lips, the rasps are remarkably efficient organs. The mononch glides up to its quarry and makes its onslaught by a quick snap of the head, throwing its jaws suddenly wide open, and grappling its prey by means of the inner armature of the lips. As the jaws close in, the victim's body is jammed against the point of the dorsal tooth, as well as against the rasps, and in this way is at once both punctured by the tooth and lacerated or milled by the rasps. In most cases the onchi seem to be solid bodies, containing no duct through which venom could empty. If any poison is injected into the victim it would seem to be derived from oesophageal glands emptying into the pharynx by some other road. The axial element sometimes seen in the onchus is probably a nerve ending.

*Minutiæ of the Wall of the Throat.* In general the wall of the pharynx is well developed and strongly refractive, and is usually thickest on the dorsal side where it gives support to the dorsal onchus; often it is very finely transversely striated. In many species this striated appearance seems to be due to a transverse lamination of the pharyngeal wall. The striation, or lamination, may be so pronounced as to give rise to transverse ridges on the interior surface of the pharynx like those of the teeth of a mill-saw file, and no doubt these ridges have somewhat the same function as the rasps just described. The onchi are sometimes seen to be longitudinally striated. The striæ of the pharyngeal walls are most clearly visible during the moulting period. In the original species-figures to follow, what appears merely as shading on the pharyngeal wall is a carefully worked-out chart of the position, number and direction of these laminations.

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<sup>a</sup> *Mylonchulus*, a small mill-tooth.

*Contour of the Maw.* The contour of the pharynx differs somewhat in the various species. If the dorsal onchus is strongly developed, the profile indicates a roughly goblet-shaped or ellipsoidal cavity, and the onchus extends well into the cavity so that its apex lies near the axis of the head, sometimes up front and close to the inner margins of the lips. If, on the other hand, the dorsal onchus is weak, and especially in species

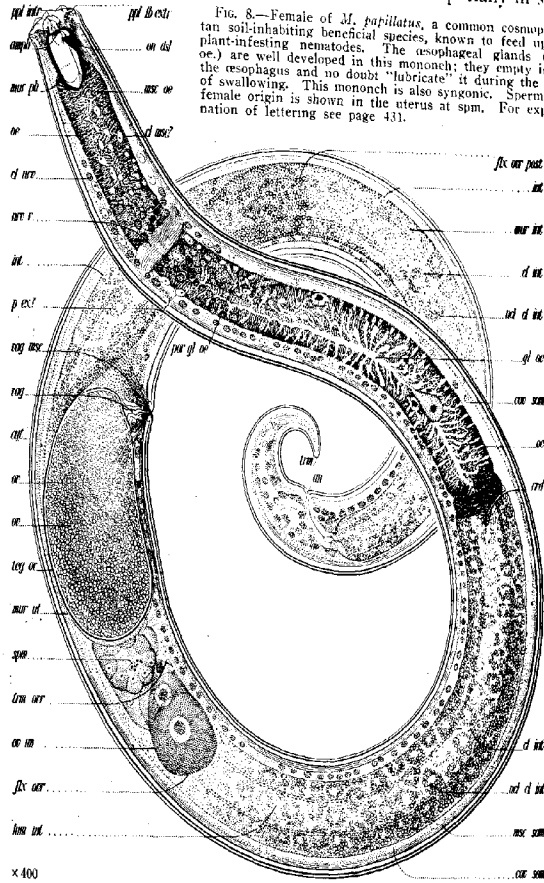


FIG. 8.—Female of *M. papillatus*, a common cosmopolitan soil-inhabiting beneficial species, known to feed upon plant-infesting nematodes. The oesophageal glands (gl. oe.) are well developed in this mononch; they empty into the oesophagus and no doubt "lubricate" it during the act of swallowing. This mononch is also syngonic. Sperm of female origin is shown in the uterus at spm. For explanation of lettering see page 431.

where the wall is not much reinforced by longitudinal ribs, the contour of the pharynx tends to be more or less oblong, so that its floor, lying in the anterior end of the oesophagus, though irregular, is likely to be, on the whole, more nearly flat. Opposite the dorsal onchus there is frequently to be seen a faint transverse seam, most prominent along the ventral side

of the pharynx, indicating a division of the wall into anterior and posterior elements. Sometimes this pharyngeal suture is rather prominent.

*Jaw Muscles.* The pharyngeal muscles of various species of mononchs have been observed, figured and commented upon by one or two investigators, but only in a vague way. Much remains to be learned concerning them. The following incomplete observations have been made in the course of these investigations.

Under suitable conditions, and especially in some species, long, slender muscles may be seen passing from the lip region backward and outward, so that their proximal attachment is to the body-wall a short distance behind the pharynx. These muscles are the flexor muscles of

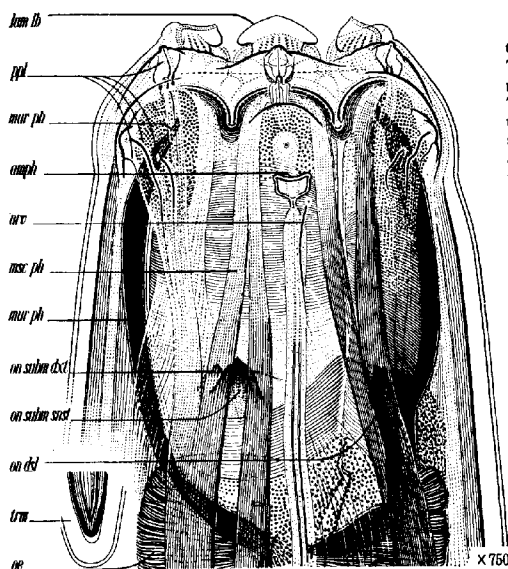


FIG. 9. — Side view of the head of *M. regius*. The lips and their appendages are well shown. The flaps (lam. lb.) are the same organs so well seen in figure 4. The amphid (amph.) extends to the bottom of the pharynx and beyond. The labial muscles (msc.) are so attached as to pull the lips both inward and outward about the stiff external ring as a fulcrum. Traces of this ring are shown arching along the margin of the anterior part of the head. Coming up from the interior of the oesophagus toward the right is seen a light-colored duct; this empties into the pharynx at its base. In this way apparently the secretion of the oesophageal glands has a direct passage to the throat.

the lips. It is certain that each lip, probably each pair of adjacent lips, is connected with a muscle whose function is to pull the lip toward the body axis about a fulcrum near the surface of the head. These muscles, then, shut the mouth. It seems likely that the elasticity of the various parts composing the frame-work of the lips and pharynx may play some part in mastication and deglutition, and act in opposition to some of the muscular elements of the pharynx. The extent to which a mononch can throw its jaws open is shown in the sketch, figure 1, made from a preserved specimen. This act is accomplished by the aid of a second similar set of muscles acting on the outside of the same fulcrum. It is unlikely

that the sketch represents the maximum gape, for the effect of chemical fixatives seems to be to lock the jaws tightly rather than leave them agape. When examined alive mononchs are seldom seen to move their mouth parts.

#### *The Mononch and Its Victim*

*Fate of Victim.* So far as I am aware, the struggle of a mononch with its victim has never been witnessed by human eyes. A struggle it must be, for mononchs are sometimes discovered that have gulped down other nemas nearly half as long as themselves. Such a dénouement must be the result of a dramatic conflict. A similar gastronomic exploit on the part of a man would be the gulping down of a string of bologna sausage several feet in length. In one instance in the course of my experience, a mononch was caught with its quarry, another nematode, still gripped in its jaws. Seized by its middle, the victim had been bitten nearly in two. This is a common fate. Sometimes, however, the ingested nema is but little mangled. I imagine the mononch swallows its prey somewhat as the python does, though less deliberately. As the œsophagus seldom occupies over one-fourth of the length of the body, and as the mononch sometimes swallows other nemas nearly half as long as itself, manifestly in such cases one end of the victim's body must reach the mononch's stomach before the other end has disappeared down its throat.

*Gluttonous Appetite.* While many mononchs bolt their food, it is evident that the food of some among them receives a certain amount of mastication, for the body of the victim is bitten into fragments and swallowed piece-meal. In some cases the degree of mastication may be greater still. Figure 10, for instance, shows the head of a preserved specimen, in the mouth of which lies a portion of the "gizzard" of a rotifer, which has been almost completely denuded of the muscular tissue originally attached to it. It is the thick-lipped species like *M. muscorum* that masticate their food in this way.

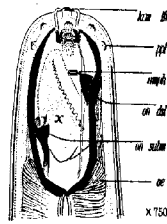


FIG. 10.—Pharynx of a female *M. palustris* with portion of the "gizzard" of a rotifer (x) being masticated.

#### *Œsophagus or Gullet*

*Lining of the Gullet. Salivary (?) Glands.* The œsophagus is more or less cylindroid, a form of œsophagus common in nemas that engorge relatively large objects. The anterior end of the œsophagus, where it receives the base of the pharynx, is usually about one-half to two-thirds as wide as the base of the head, and is occasionally somewhat swollen, so that one may speak with propriety of an obscure pharyngeal bulb. The œsophagus has nearly the same diameter throughout the greater portion of

its length; it may diminish a trifle in the vicinity of the nerve-ring, while, in the posterior half it usually expands a trifle, so that finally it is one-half to two-thirds as wide as the corresponding portion of the body. The refractive lining of the œsophagus is strongly developed, and is of such a character that its longitudinal optical section often occupies as much as one-third of the diameter of the whole organ, sometimes one-half, exceptionally even more. The radial musculature of the œsophagus is strongly developed, and usually appears coarser posteriorly than anteriorly.

*Œsophageal Glands.* In some species, very likely in all, among the interstices of the œsophageal muscles there exist glandular tissues, which empty their secretion into the lumen of the œsophagus through minute pores in the lining, situated from place to place throughout a considerable portion of the length of the organ. Some of these glands appear to empty into the pharynx, but the best developed ones occur in the dorsal section of the œsophagus near the middle.

De Man and Micoletzky mention structures in the wall of the pharynx of *Mononchus*, about the nature of which they seem doubtful, but suggest the possibility that they are pores. My observations lead me to the conclusion that some of the more minute so-called "teeth" or denticles of authors, at the bottom of the pharynx, and even some of those higher up, are in reality elevated pores connected with glandular structures in the anterior part of the œsophagus. These pores appear to me to be the homologues of the pores which I have demonstrated undoubtedly to exist farther back in the œsophagus, and to be the outlets of glands located in the interstices of the radial muscles. See fig. 9.

It is easy to believe that the œsophageal glands are salivary glands, and that they serve the mononchs in gorging down food in somewhat the same way as do the glands of serpents. This surmise is based upon the structure and position of the organs rather than upon definite and extensive physiological experiment; intra vitam stains, however, have shown that the secretions of these glands are alkaline,—evidence supporting the surmise.

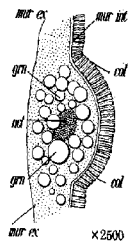


FIG. 11.—Portion of cross section of intestine of *M. longicaudatus* to show columnar structure of the lining of the intestine, col.

#### Intestine

*Cardia.* There is usually a flattish cardia consisting of 20 to 50 small characteristic cells that stain rather strongly with acid carmine, and manifestly discharge a distinct function. The intestine, which is invariably separated from the œsophagus by a deep and prominent constriction, becomes at once about three-fourths as wide as the body, and is usually made up of cells of such a size that about 8 to 20 are required to build a circumference. These cells contain numerous granules of somewhat variable size, often so arranged

about the large central nucleus as to give rise to a beautifully regular appearance simulating tessellation. As a rule, the columnar lining of the intestine (fig. 11) is not very refractive. Owing to the low visibility of this lining, and the difficulty of seeing through the mass of granules contained in the intestinal cells, the lumen is usually hard to decipher; toward the anus, however, it may become more distinctly visible. Occasionally, the granules are so few or so transparent that the contents of the intestine can be seen with ease, but this is rather exceptional.

*Granules.* The structure and arrangement of the granules in the intestinal cells of *Mononchus lacustris* may be taken as somewhat typical. The granules of this species are numerous and packed rather closely in the cells, and give rise to a more or less distinct tessellation. Specimens fixed with Flemming solution, and mounted in glycerine jelly, show many of the granules as refractive shells, enclosing a relatively large inner spherical mass, which appears dark or light according to the nature of the focus of the microscope. This structure is characteristic of some of the smallest, as well as some of the largest, granules. These appearances are not uniform throughout the intestine, the shell-like structures being more apparent in the posterior part than elsewhere, and less apparent through the middle portion of the body, where the granules are largest and most abundant.

These intestinal granules play an important role in the economy of the nema—some of them are in fact indispensable intracellular organs. Little as we know about their functions in detail, it is already certain that they have to do not only with the secretion of various digestive fluids, but also with the transformation and storage of the digested matter. The granules in any given cell may be of several kinds, doubtless serving entirely different functions. These facts the author has demonstrated by intra-vitam staining.

#### Digestion

*Food Remnants.* The digestive fluids of the mononch must be well fitted for dissolving ceratin, supposedly the main component of nematode cuticle, for the cuticle, as well as most other parts of the ingested victim, disappears completely in the course of digestion. The parts that resist digestion longest are the spicula of male nemas and the oral spears of the spear-bearing sorts. These organs, the spicula and the spear, are composed of relatively thick layers of solid "ceratin," and furthermore are protected from the action of the digestive fluids because of their situation in the interior of the ingested nema, and hence are among the last to be dissolved. Such an undigested remnant, a spear or a spiculum, consti-



FIG. 12.—Vulva region of *M. major* showing vulvar papillae,  $\gamma$  ppl.



tutes one of the most frequent, as well as most reliable, bits of evidence concerning the food-habits on mononchs.

*Voracity.* Mononchs are voracious. Often the remains of several other nemas are to be seen in the intestine of a single one of them. The writer once had under observation a specimen that had swallowed four large rotifers in quick succession, all tail-end first. The file of rotifers could be clearly seen in the intestine of the mononch. Aquatic mononchs are fond of rotifers. The characteristic "gizzards" of the rotifers, being rather indigestible, are often found in the posterior part of the intestine.

*Rectum.* From the slightly depressed anus, the lips of which are sometimes rather pronounced, the refractive rectum, usually about as long as the anal body diameter, extends inward and forward, and is separated from the intestine by a distinct constriction. There is no pre-rectum, though the contrary impression is sometimes created by a constriction caused by a mural commissure (?) some little distance in front of the rectum.

*Feces.* From the region of the anus relatively powerful transverse muscles pass obliquely backward to the body wall, and find their proximal attachment in the dorsally submedian regions. These anal muscles are more strongly developed in mononchs than in most nemas. A powerful defecating apparatus is needful to such gluttons, since their feces are sometimes bulky, owing, apparently, to the fact that the contents of the intestines of their victims often prove indigestible. Probably this indigestible material is to a considerable extent vegetable in its nature; at any rate, it frequently happens that the feces are bulky, and this fact seems to account for the strong development of the rectum and the anal muscles.

#### *Caudal Glands; Spinneret*

*The Cement.* The caudal glands, when present, are always three in number, and are arranged in a cluster or series opposite to or immediately behind the anus. If the tail is short, the foremost gland is usually

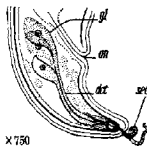


FIG. 13.—Mononch tail showing the three caudal glands, their ducts, the spinneret, and its secretion (sec.).

dorsal while the two submedian glands are arranged side by side; if the tail is long all three may be arranged tandem. Apparently there are always three separate ducts, one from each gland, each having a separate ampulla; these latter are arranged side by side in a group at the spinneret. Often, however, the spinneret is simple in form and presents ducts that form only indistinct ampullæ. Some idea of the manner and rate of secretion of the caudal glands may be derived from an examination of the adjacent illustration, which shows a spiral mass of the cement substance secreted by them. This spiral mass was coagulated by the fixing fluid in which the specimen met its death.

*Action of Spinneret.* The structure of the spinneret is very similar to that of *Mononchulus*, a related genus whose unusually large spinneret has proven especially favorable for detailed study, and may be described as follows. The three somewhat elongated ampullæ at the ends of the caudal ducts empty into a single sac located in the spinneret. From the front wall of this sac there projects backward into its cavity an elongated element whose free conical distal extremity fits into the outlet of the spinneret, where it acts as a plug or valve. Apparently, this valve must arise through an invagination of the sac during development. The plug is withdrawn by muscles attached to it and to the dorsal body-wall near the end of the tail. A contraction of these muscles elongates the sac containing the caudal secretion and draws the plug away from the aperture of the spinneret, thus allowing the secretion to flow out through the terminal pore. The plug appears to be returned to its position and held there either by the pressure of the secretions in the sac, or by the general internal body pressure exerted on it through the sac. Figure 5 shows the similar spinneret of a mononch.

*Use of Spinneret.* In any genus consisting of many species most of which have caudal glands, aberrant species usually occur in which these organs are absent. This is true of *Mononchus*. A spinneret would appear to be a particularly useful organ to a predaceous nema, permitting it at will instantly to cement itself to a relatively fixed object, and thus more easily master an active victim; nevertheless, about one-fourth of the mononchs have no trace of such an organ.

The lateral fields are always comparatively well-developed, and are usually one-third to one-fourth as wide as the body. The cells composing them often contain spherical granules not differing greatly in size from those of the intestinal cells. No cuticular pores have ever been seen connecting elements of the lateral fields with the exterior.

#### *Renette*

Nothing is known about the structure of the renette—in fact, it is not yet definitely known to exist in mononchs. In most species there is a ventral pore immediately behind the nerve-ring, which bears a close resemblance to the excretory pore of nemas possessing a well-developed renette; but no internal structures have as yet been found to connect with this pore.

#### *Central Nervous System*

The nerve-ring surrounds the œsophagus somewhat squarely near the front end of the middle third of the neck. It is usually well developed and easily seen—a distinct refractive collar with groups of nerve cells both in front of it and behind it. Otherwise than this very little is known about the central nervous system of *Mononchus*.

*Nerve Commissures.* A constriction in the intestine is sometimes observed at a point not far in front of the rectum, say at a distance equaling 3 to 5 body diameters. This constriction is sometimes so pronounced as to cause the posterior portion of the intestine to simulate the pre-rectum of *Dorylaimus*. There is here, however, no true pre-rectum. The constriction seems to be caused by mural commissures surrounding the intestine. The writer can only suggest the possibility of the existence of special nerves at this point, which leave the ventral field, pass slightly backward, then almost immediately become squarely transverse, encircling the intestine until they are very near the dorsal field, where they turn suddenly backward.

#### Amphids

It is almost certain that small amphids occur on all mononchs; the writer found them present on three-fourths of the known species. As their general characters have never been adequately described, their form and position are specially noted here, as well as more explicitly in the various illustrations. The external indications of the amphid are always located

on the lateral lines somewhere between the base of the lips and a point opposite the middle of the pharynx. The periphery, which in some cases may be unclosed behind, is usually more or less elongated or elliptical in form, its long axis lying transversely on the head. These amphids are seldom more than one-sixth as long as the head is wide, and are usually

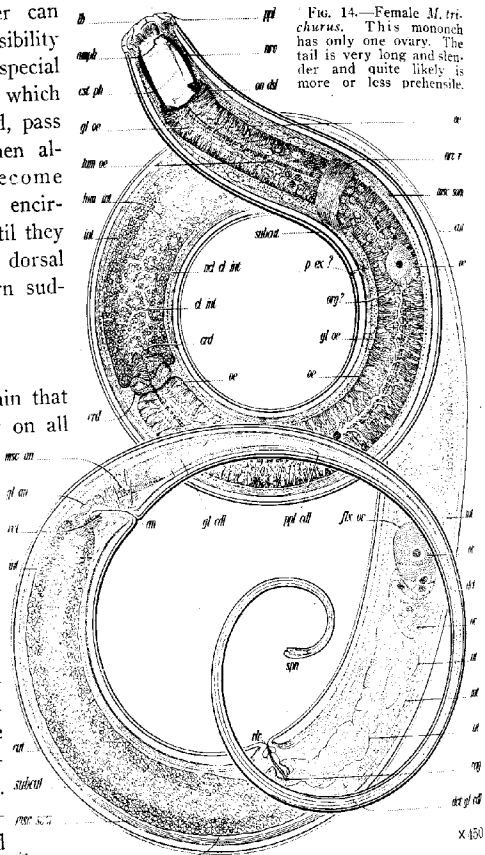


FIG. 14.—Female *M. trichurus*. This mononch has only one ovary. The tail is very long and slender and quite likely is more or less prehensile.

very difficult of observation. They are most easily detected when viewed dorso-ventrally, and then appear as refractive oblique elements leading from the surface of the head inward and backward through the transparent cuticle, as shown for instance in the cases of *tenuis* and *regius* (p. 469 and 442). They can seldom be followed more than a short distance inward, and their ultimate internal connections are unknown. A nerve-ending is nearly always to be seen in the cuticle immediately behind each amphid.

#### *No Eyes*

Mononchs have no definite organs of vision.

#### *Female Sexual Organs*

*Organs Mostly Double. Eggs. Ovaries and Ova.* From the slightly elevated and rather small vulva, the prominent refractive vagina leads inward at right angles to the ventral surface about one-third the distance across the body. Though comparatively small in size, the vulva is usually easily located on account of the refractive nature of the walls of the vagina. In nine-tenths of the species, the internal female organs are double, and symmetrically reflexed, though in some cases the posterior branch is somewhat smaller than the anterior. In the exceptional species the single ovary is also reflexed (fig. 14). The ovaries occupy relatively less space than is usual in nemas—less than one-fourth of the length of the body. Owing to the comparatively great length of the neck, the vulva is usually located somewhat behind the middle of the body even when the sexual organs are double and symmetrical, and may occur as far back as the junction of the third and final fourths. Each of the two uteri is about twice as long as the body is wide, that is to say, of a size to receive one or two eggs only. These latter are nearly always smooth, thin-shelled, ellipsoidal or elongated in contour, and appear about twice as long as the body is wide, though they are sometimes somewhat shorter, and more rarely longer. Only in a single species are the shells known to be sculptured. The shells are thick in *obliquus*. In all the species examined by the writer, the eggs are deposited before segmentation begins, and this is presumably true of the great majority, if not of all the species. The reflexed ovaries extend one-half to three-fourths the distance back to the vulva and contain a score or so of ova, which near the blind ends are packed in several rows—ova that by increase in size come, each one in turn, to occupy the whole of the width of the organ in its proximal half near the flexure. The ovaries are rather broad, and taper relatively little.

*Syngonism.* A considerable number of the mononchs are syngonic, and it is probable nearly all of them are so, since the males, if found at all, are nearly always rare. Only on a single occasion, so far as records go, have males been found to be as common as the females. Of most species

the males never have been seen. At a time previous to the development of the vulva the gonads of the female produce minute spermatozoa, which are sent forward and stored in a special portion of the uterus next the proximal end of the ovary. In the only species so far carefully examined in this regard these minute spermatozoa are known to be functional, at least to the extent that they enter the ova, which then proceed to form polar bodies and begin to segment. However, these particular investigations, made by the author and further recorded in figure 2, have been confined to the single species *M. longicaudatus*. Possibly the phenomena are different in other species.

### Male Sexual Organs

*Spicula.* The tail end of the male is invariably like that of the female in general form and size, except that it is more strongly arcuate; it differs however, in some instances, probably in all, in the possession of

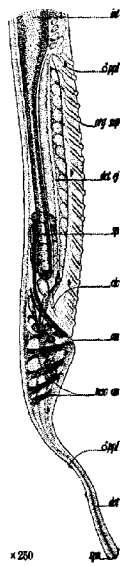


FIG. 15.—Tail end of *M. obtusus* after Bütschli. The spicula in this species are exceptionally long and slender. The male papillae (mpl.) and supplementary organs are very well shown. The spicula are protrudable and are guided by slender accessory pieces half as long as themselves—also shown.

comparatively well-developed papillae, and particularly and universally in the existence of a ventral row of 8 to 20 more or less equidistant supplementary organs immediately in front of the anus. The two well-developed arcuate spicula are of equal size, and are always accompa-

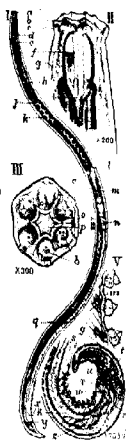
nied by two distinct though small accessory pieces, a right and a left. Only exceptionally are the spicula long and slender; usually they are somewhat uniformly arcuate, and appear to be subacute and of somewhat uniform width throughout, at least when viewed in profile, and about one and one-half times as long as the anal body diameter. Usually each is strengthened by a median longitudinal refractive piece. They are never prominently cephalated. The accessory pieces are located some little distance inside the anus, alongside the spicula, which they may appear to cross when viewed in profile. These accessory pieces are usually a little narrower than the spicula, and 2 to 4 times as long as wide. Distally they usually end in two subacute points, often so arranged as to form a small U-shaped figure. When at rest the accessory pieces usually appear as if at about right angles to the axis of the body. They are not cephalated.

*Supplementary Organs. Sperm.* The supplementary organs vary in number up to twenty. The hindmost is located immediately in front of the anus, and may be a little farther removed from its nearest neighbor

than is usually the case in the remainder of the series; thence forward the organs are about equidistant. Usually they are more or less contiguous, though occasionally they are separated by short spaces, especially anteriorly. When most highly developed, each is a convex-conoid, innervated, very minutely papillated or echinulate, more or less protrudable organ, connected with the interior by an oblique, indistinct element along the axis of which a nerve passes inward and forward to join the ventral nerve of the body (v, fig. 16). It would appear that these organs are partly tactile and partly excitatory in function, and act as the complements of the vulvar papillæ of the female. There is no bursa. The series of oblique copulatory muscles is always coextensive with the series of supplementary organs. The rather short testes seem to be invariably two in number and are outstretched in opposite directions. The spermatozoa of males are minute and present a more or less vermiform nucleus.

FIG. 16.—*Mononchus major*. I.—Side view of male. II.—Side view of head of same. III.—Front view of head. IV.—Side view of tail. V.—Details of male supplementary organs.

a, mouth  
b, lip-papilla  
c, lip  
d, oesophagus  
e, nerve-ring  
f, pharyngeal tooth  
g, innervated papilla of skin  
h, oesophagus  
i, base of pharynx  
j, cardiac collum  
k, intestine  
l, flexure in testicle  
m, blind end of testicle  
n, vas deferens  
o, lip  
p, mouth opening  
q, ejaculatory duct  
r, spicula  
s, ejaculatory duct  
t, accessory piece  
u, post-anal papillæ  
v, spicula  
w, ejaculatory duct  
x, ventral row male papillæ  
y, anus  
z, three anal glands



#### Self-Fertilizing Females; Syngonism

*Males Rare. Conjugation of Syngonic Gametes.* No trait of mononchs is more interesting than the capacity of the female to reproduce without the intervention of a male—by a peculiar sort of hermaphroditism called syngonism. Of most of the species no males are known; in the remaining species, almost without exception the males are very scarce, and only in exceedingly rare cases are they present in anything more than small numbers. Usually hundreds, and even thousands, of specimens may be examined without the discovery of a single male. How then do the females reproduce? The answer is singularly interesting, for, as already explained, the females fertilize their own eggs by means of spermatozoa which they themselves produce in the same gonad. In the mononchs these spermatozoa produced by females are so exceedingly minute that they have hitherto escaped notice (fig. 2). Notwithstanding its small size, the syngonic sperm cell appears to be functional. It enters the egg, expands, and approaches the nucleus of the egg, which meanwhile throws off polar bodies and later proceeds with segmentation. Observations have not yet extended beyond this point, but it seems alto-

gether likely that these minute spermatozoa produced by mononch syngones act in what would be called a normal manner, and as the spermatozoa are known to do in other syngonic nemas in which they are of much larger size, *e. g. Rhabditis*.

#### *Abundance; Distribution*

*Frequency of Mononchs.* Long ago Bütschli declared mononchs to be among the commonest of nemas, an assertion that has been corroborated by all investigators in this field, hardly any of whom have failed to note a number of species, occasionally new ones. Our knowledge of the genus has been augmented in this way by de Man, Micoletzky, Ditlevsen, Steiner, Hofmänner, Menzel, Daday, and the writer, until at the present time about sixty species are known. Doubtless this number will be very largely increased by future researches.

*Geographic Distribution. Variety of Habitat.* Mononchs are found in all the habitable regions of the world. They inhabit the soils and fresh waters of every clime, occurring even at great depths in lakes and at very high altitudes on mountains. While we have only just begun to learn the details of their geographic distribution, it is already manifest that some species are cosmopolitan. Several species occur both in Europe and in North America, and a few of these same species are known also from Australia. Considering the small number of observations hitherto made along this line, it seems safe to predict that many of the species will be found to be cosmopolitan. Some species adapt themselves to surprisingly varied conditions. *Mononchus longicaudatus*, for instance, is known from the tropics, from temperate regions, and from very cold regions, and inhabits both soil and fresh water. Another species, *Mononchus brachyuris*, is known both from warm springs and from cold Alpine lakes.

*Abundance in Arable Soil.* Mononchs occur in great numbers in arable soil. On one occasion the writer estimated that at least thirty millions of mononchs per acre were present in the top six inches of a field of maize in New Jersey, and the actual number present may have been much greater. They are regularly present in practically all arable land of a sandy or loamy nature.

The very numerous introductions of living plants into the United States, through the agency of the Office of Seed and Plant Introduction of the Department of Agriculture and other agencies, has brought about simultaneously the introduction of many species of *Mononchus*. Nemas existing in the soil about the roots of introduced plants are often placed under favorable conditions for propagation in this country. It is therefore certain that an unusual variety of mononchs exists in the soils of the United States.

*Interplay of Organisms.* There are regions where certain nematode diseases of crops are very destructive, while other regions, the climate and soil conditions of which are apparently similar, suffer but little, or at least to a lesser degree, so far as we know. In such cases it is permissible to suppose that the nematodes in the area where the lesser damage is done are held in check by some as yet unknown agent. Is it not possible that the mononchs play some such rôle as this, and that just as certain insects hold other insects in check, so certain nemas hold other nemas in check?

We know relatively little about the life history of most of the mononchs, and as yet very little about the possibility of controlling their growth. One species, *Mononchus longicaudatus*, occurs at certain times in almost inconceivable numbers in the sand of the slow filter beds of the water works of cities. Near the end of the period of use the top layers of the sand in these filter beds sometimes become in reality a huge culture of this species. The observations suggest at least the possibility of cultivating this species on a large scale, should it prove desirable to do so.

The discovery that the genus *Mononchus* is very large and to a considerable extent composed of common and cosmopolitan species that feed upon injurious plant-infesting organisms, suggests so many new lines of research in soil biology as to make it desirable that a clear and connected account of the members of the genus be available to investigators. This need is increased by the fact that the literature is a scattered and fragmentary one, difficult to assemble. To these facts it must be added that most of the new observations herein recorded have been made upon species previously unknown.

## II

### GENUS MONONCHUS BASTIAN, 1866

This genus is composed of non-marine, free-living nemas, with naked cuticle and obscure amphids, and having a plain cesophagus preceded by a broad—that is, non-tubular—pharynx, armed with 1 to 3 more or less immobile teeth of which the dorsal is largest, and supplied with 6 powerful palliated lips. Ovaries reflexed, usually two. Testes two, outstretched; spicula two, equal, simple, as are their small accessories; there is a pre-anal ventral row of supplementary organs.

#### GENERA SIMILAR TO MONONCHUS, WITH DISTINGUISHING CHARACTERS

<i>Oncholaimus</i>	Marine; sometimes found in brackish soils. Has cephalic setæ.
<i>Anonchus</i>	Has spiral amphids, and cephalic setæ.
<i>Microaimus</i>	No thick muscular lips; amphids circular.
<i>Ironus</i>	Pharynx tubular; teeth movable radially.
<i>Nannonchus</i>	Has spiral amphids and cephalic setæ.
<i>Gionchus</i>	Pharynx filled by single tooth, which is really spear-like.
<i>Mononchulus</i>	Quite similar. Has much larger (ventral) spinneret; strongly developed lateral fields; smaller pharynx; female organ single.



*Mononchus* Bastian, 1866

		Subgenera and Species	
<b>DORSAL TOOTH</b> midway in pharynx or higher, usually massive		1. <i>MONONCHUS</i>	
<b>Tooth</b> not opposed by denticles; subg. <i>MONONCHUS</i> Cobb;			
type, <i>M. truncatus</i> Bast.; pharynx about 2 to 3 times as			
long as wide, goblet-shaped or ellipsoidal; wall smooth or			
transversely striated; spinneret usually present; males of			
about half the species known; female organs double (except			
<i>monhystera</i> )			
Dorsal tooth faced by 2 ventrally submedian teeth		(tridentatus de Man 1876)	43
Teeth retrorse			
Teeth not retrorse			
Tail conoid, then cylindroid; body 7 mm. long.		(rex Cobb 1904)	51
Tail simply conoid; body 3 mm. long or less			
Spinneret and caudal glands absent		exilis n. sp.	1
Spinneret and caudal glands present			
Contour of the head angular; labial papillae 16		radiatus n. sp.	2
Contour of the head rounded; labial papillae 12			
Pharynx longer than the head is wide.		palustris n. sp.	3
Pharynx only as long as the head is wide.		teres u. sp.	4
Dorsal tooth not faced by submedian teeth			
Ovary 1; pharynx not much longer than wide.		monhystera n. sp.	5
Ovaries 2; pharynx toward twice as long as wide			
Tail simply conoid, 8 per cent or less			
Spinneret none			
Pharynx over half as wide as the head.		vorax n. sp.	6
Pharynx not over half as wide as the head			
Length about 1 mm.; tooth midway, small, digitate		parvus de Man 1879	7
Length 1.5 to 2 mm.; tooth beyond midway, massive		papillatus Bastian 1866	8
Spinneret present			
Body 2 mm. long			
Form of the tail regular		intermedius Cobb 1893	9
Form of the tail somewhat irregular		tenuicaudatus Stefanski 1914	10
Body 3 to 4 mm. long			
Tooth midway, amphids a little behind the lips		major Cobb 1893	11
Tooth and amphids at the base of the lips.		gerlachei de Man 1904	12
Tail conoid, then cylindroid, about 10 per cent or more			
Oesophagus 15 per cent		fovearum (Dujardin) Bastian '66	13
Oesophagus 22 per cent or more			
Buccal cavity toward 2 times as long as head is wide			
Spinneret armed with 2 very small setae.		megalaemus n. sp.	14
Spinneret not armed with setae.		macrostoma Bastian 1866	15
Buccal cavity only about half as long as head is wide			
Labial papillae setose		obtusum n. sp.	16
Labial papillae, at least the outer, not setose			
Pharynx $\frac{1}{2}$ as wide as head; body 1.5 mm. long		tunbridgensis Bastian 1866	17
Pharynx $\frac{1}{2}$ as wide as head or more; body 2 to 3 mm.			
Cavity about 2 times long as wide; tooth acute		truncatus Bastian 1866	18
Cavity about 3 times as long as wide; tooth sub-acute			
Inner labial papillae large; tail sub-conoid.		dadayi Micoletzky 1904	19
Inner labial papillae normal; tail finally cylindric		longicaudatus Cobb 1893	20
<b>Tooth</b> opposed by numerous denticles on opposite wall			
Arrangement of the denticles irregular; characters otherwise		2. <i>SPORONCHULUS</i>	
as in <i>Mylnchulus</i> ; subg. nov. <i>SPORONCHULUS</i> ;			
type <i>S. dentatus</i> n. sp.			
The tooth behind midway; spinneret present; anus at 92; f		recessus	21b
The tooth in front of midway; no spinneret; anus at 96;			
Denticles about 20; pharynx half as wide as the head; 'P		dentatus	21a
Denticles about 50; pharynx one-third as wide as the head		decurrens	21c
Arrangement of the denticles orderly			
Denticles along a ventral, longitudinal pharyngeal rib;			
subg. <i>PRIONCHULUS</i> Cobb; type <i>Pr. muscorum</i>			
(Dui.) Bast.; pharynx ellipsoidal, about 2 times long		3. <i>PRIONCHULUS</i>	
as wide; males of one species known; female organs			
double; no spinneret			
Eggs punctate or echinulate		punctatus n. sp.	22
Eggs not punctate or echinulate			
Length 2.5 to 3.4 mm.; vulva at 65 per cent; anus at			
94 per cent			
Width 3.6 per cent; denticles forward pointing.		muscorum (Dujardin) Bast. '66	23
Width 2.3 per cent; denticles inward pointing.		longicollis n. sp.	24
Length 4 mm.; vulva at 55 per cent; anus at 97 per cent		spectabilis Ditlevsen 1911	25
Denticles in transverse rows on 2 sometimes confluent sub-			
median, rasp-like areas, often with 2 very small sub-			
median teeth at their bases; subg. <i>MYLONCHULUS</i>			
Cobb; type <i>M. minor</i> Cobb; pharynx goblet-shaped,			
tooth more or less arcuate; smaller species of which			

the males are unknown (except <i>tenuis</i> ); female organs double (except <i>index</i> and <i>reversus</i> ); spinneret present (except <i>similis</i> )		
Ovary 1; tail rapidly diminished, then digitate		
Vulva behind the ovary; denticles normal	Index Cobb 1907	26
Vulva in front of the ovary; denticles few	<i>reversus</i> n. sp.	27
Ovaries 2; tail not digitate (Ex. perhaps <i>sigmaturus</i> )		
Dorsal tooth somewhat digitate, relatively small		
Refractive ring about pharynx in front of tooth	<i>obtusicaudatus</i> Daday 1901	28
Refractive ring about pharynx not prominent	<i>brachyuris</i> Butschli 1873	29
Dorsal tooth massive, not digitate		
Head rounded, denticles in about 12 rows	<i>denticulatus</i> n. sp.	30
Head truncate, denticles in 2 to 6 rows		
Rows of denticles 2		
Rows of denticles 4 to 6	<i>sparsus</i> n. sp.	31
Denticles about 4 rows; spinneret small	<i>micurus</i> n. sp.	32
Denticles about 6 rows; spinneret larger		
Tail bent ventrally near the middle		
Caudal setae none; tail conoid	<i>incurvus</i> n. sp.	33
Caudal setae (3 pairs) present; tail not conoid	<i>sigmaturus</i> n. sp.	34
Tail arcuate or straightish		
Width of adults 2.3 per cent	<i>tenuis</i> n. sp.	35
Width of adults 2.7 per cent or more		
Caudal glands and spinneret absent	<i>similis</i> n. sp.	36
Caudal glands and spinneret present		
Eggs thick shelled	<i>obliquus</i> n. sp.	37
Eggs thin shelled		
Buccal strie faint if any; anus 94 to 96 per cent		
Species aquatic	<i>lacustris</i> Cobb 1915	38
Species not aquatic	<i>molonicus</i> Stefanski 1915	39
Buccal strie more pronounced; anus 98 per cent	<i>minor</i> Cobb 1893	40
Spinneret finally dorsally recurved	<i>brevicaudatus</i> n. sp.	41
Spinneret not dorsally recurved	<i>japonicus</i> n. sp.	42
<b>DORSAL TOOTH</b> and others small, basal or nearly so (Ex. 44)		
<b>Teeth retrorse</b> , small, basal, exceptionally midway; submedian teeth; tail long and usually becoming cylindroid; female organs double; males of most of the species known		
Body 2 to 4 mm.; teeth equal, midway; anus 90 per cent	<i>tridentatus</i> de Man 1876	43
Body 5 to 6 mm.; teeth sub-basal; anus 80 to 85 per cent		
Submedian teeth equaling the dorsal; body 6 mm.	<i>gracilicaudatus</i> n. sp.	44
Submedian teeth smaller than the dorsal; body 5 mm.	<i>dolichurus</i> Ditlevsen 1911	45
<b>Teeth not retrorse</b> , small, or even minute; submedian teeth		
Cobb; type <i>I. gymnolaimus</i> Cobb; large species with roomy elongated pharynx having longitudinal ribs; tail rather long, and often slender; males of more than half the species known; female organs double or single; most species with spinneret		
Ovary single; 1 to 3 rudimentary basal teeth		
Tail digitate; 3 sub-equal vestigial teeth	<i>digiturus</i> Cobb 1893	46
Tail not digitate; 1 dorsal tooth, remainder faint or none	<i>trichurus</i> n. sp.	47
Posterior extremity setaceous		
Posterior extremity slender but not setaceous	( <i>bathybius</i> Micoletzky 1913)	
Pharynx as long as wide; few submedian denticles		
Pharynx about 2 times long as wide; faint submedian teeth		
Amphid simple; buccal wall thin, transversely striated	<i>gymnolaimus</i> Cobb 1893	48
Amphid duplex; buccal wall thick, not striated	<i>consimilis</i> n. sp.	49
Ovaries 2; 1 to 3 small, sub-basal teeth		
Body 4 to 7 mm.; tail finally cylindroid; 3 teeth		
Spinneret present; lips rather plain	<i>rapax</i> n. sp.	50
Length 4 mm.; anus 90 per cent; the 3 teeth subequal		
Length 6 to 7 mm.; anus 80 per cent; submedian teeth smaller	<i>rex</i> Cobb 1904	51
Spinneret none; lips striated lengthwise	<i>regius</i> n. sp.	52
Body 1 to 4 mm.; tail conoid; 1 tooth, sometimes denticles		
Anus at about 86 per cent; tail finally sub-cylindroid	<i>bathybius</i> Micoletzky 1913	53
Anus at about 94 per cent; tail simply conoid		
Dorsal tooth small, others basal, minute, indefinite	<i>studer</i> Steiner 1914	54
Dorsal tooth distinct		
Buccal cavity half as wide as long; tooth sub-basal	<i>zschokkei</i> Menzel 1913	55
Buccal cavity as wide as long; main tooth basal		
Spinneret present	<i>hrachylaimus</i> n. sp.	56
Spinneret none	<i>acutus</i> n. sp.	57

## 5. MYLONCHULUS

## 5. ANATONCHUS

## 6. IOTONCHUS

\*\* The species figures have the same magnification throughout, so that the reader may gauge the relative sizes.

4. *M. teres*, n. sp. This comparatively small, simple form has 2 submedian teeth of equal size. Walls of the intestine with numerous granules of rather uniform size, giving rise to a faint tessellation; the granules such that 2 to 3 would be required to span one of the 3.9 12. 35. 60<sup>7</sup> 94. → .8 mm  
3.4 3.6 3.5 3.2 2.7  
amphids. Tail rather strongly arcuate, its fairly well developed spinneret about one-fifth as wide as its base. Caudal glands somewhat elongated, their small but rather conspicuous ampullæ nearly filling the posterior fifth of the tail.

Description prepared from a single, more or less shrunken specimen, found in the sphagnum of a pot in which blueberry plants were being cultivated. Bears a general resemblance to *papillatus*, but differs in the form of the pharyngeal teeth and of the terminus. Flemming solution to glycerine. Fig. 19.

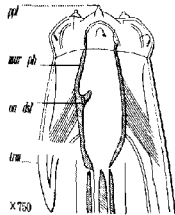
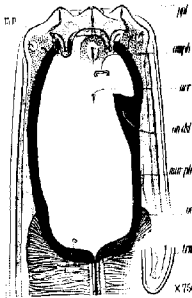
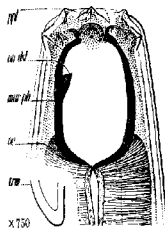
5. *M. monhystera*, n. sp. Amphids not seen. Lining of the rectum and of the intestine rather distinct and refractive. Intestine only faintly tessellated, if at all. 3.3 9.7 27. \*7819 94. Tail arcuate, rather  
3. 3.3 3.6 3.2 2.3 1.1 mm blunt, without spinneret. From the rather conspicuous, more or less elevated vulva, the vagina, which is two-thirds as long as the body is wide and tubular, extends obliquely inward and forward. Nothing definite is known with regard to the eggs or the form of the ovary.

Found about the roots of orange trees, Bahia, Brazil. Bears a general resemblance to *M. papillatus*, but has only one ovary. This species is nemativororous. Flemming solution to glycerine. Fig. 20.

6. *M. vorax*, n. sp. This voracious species has a large mouth cavity and the esophagus is therefore at first slightly swollen. Intestine 12 to 20 cells in girth, not tessellated. The 2.7 8. 27. \*87\*22 92. 1.4 mm  
2.1 2.3 2.7 2.6 1.6  
terminus of the arcuate tail is about one-seventh as wide as its base. The elongated eggs are about twice as long as the body is wide. Each ovary contains about 30 developing ova, arranged irregularly. Small sperm cells were seen in abundance at the flexure, in a condition indicating that the species is syngonic.

Found in soil from a white cedar swamp in Wisconsin, and from a cranberry bog in New Jersey, U. S. A. This is apparently a voracious feeder on other nematodes. Remains of *Dorylaimus* and *Ironus* were seen in the intestine. Resembles *M. macrostoma*, but the tail is conoid and has no spinneret. Sublimate to balsam. Fig. 21.

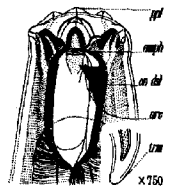
7. *M. parvus* de Man. De Man mentions the presence of minute teeth at the base of the pharynx, near the beginning of the esophagus. Lining of the 3.1 9.5 29. \*63\* 93. 1.1 mm  
3. 3.6 4.7 5.2 3.  
esophagus well developed. Intestine apparently about 10 to 12 cells in girth, tessellated. Rectum somewhat shorter than the anal body-diameter. Tail arcuate; its terminus only about one-eighth as



wide as its base. An egg seen in the uterus measured  $100\ \mu$  in length. It is not certain that caudal glands are present.

Knowledge of this species rests very largely on the observations of Dr. J. G. de Man, who says that it is an active species, common in sandy soils of the dune districts of Holland. Occurs also in Germany, according to Brakenhoff, whose specimens, however, have the dorsal tooth close to the lips instead of midway as in the type form. Fig 22, previous page (after de Man).

8. *M. papillatus* Bastian. Glands are present in the segments of the œsophagus, and are most strongly developed in the posterior half. The secretion of the glands



in the dorsal segment of the œsophagus through a minute pore near the middle of the neck, a short distance behind the nerve-ring. Under favorable conditions lenses of the highest power show transverse striae to be interrupted on the lateral lines, where there are 2 refractive longitudinal striations very close together. What appears to be an ordinary ventral renette pore is found a short distance behind the nerve-ring. The writer's investigations prove this species to be syngonic. The longitudinal ribs of the pharynx, probably 3 in number, are a little more prominently developed than usual. Occasionally a subventral or submedian rib of the pharynx shows traces of most exceedingly fine denticles. Only the most careful examination of favorable specimens shows these denticles. The writer has never observed a denticulated ventral rib like that of *muscorum*, as mentioned by Menzel.

A common, voracious, cosmopolitan, nemativorous species. Found in many parts of Europe and of the United States, and also in Hawaii, Australia, South America and Asia. Fig. 23. See also fig. 8.

9. *M. intermedius* Cobb. Truncate head having 6 lips, each with 2 papillae. The elongated-oval amphids are half as wide as the base of the lip. The rather long, goblet-shaped pharynx is half as long as the head is wide, and presents a moderate-sized dorsal tooth two-thirds the way from the base to the lips. The intestine, whose commencement is marked by the presence of a pseudo-bulb, shows a rather indistinct tessellation. What appears to be a ventral renette pore occurs just behind the nerve-ring. The lateral fields are one-fourth as wide as the body. Caudal glands are present in the conical, arcuate tail. Spinneret almost pointed. Anus depressed, consequently conspicuous. Vulva conspicuous. The reflexed portions of the ovaries extend one-half way back to the vulva.

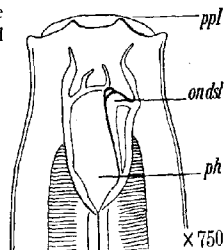
Found about the roots of sugar cane, Harwood, Clarence River, New South Wales, Australia. Examined in water after fixation with osmic acid vapor.

10. *M. tenuicaudatus* Stefanski. The lips are said to bear 6 large, spheroidal papillae. A transverse element is said to traverse the wall of the pharynx opposite

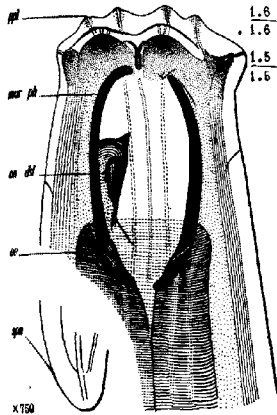
the apex of the dorsal tooth, and

to bear 2 slightly curved projections. The œsophagus is muscular. At first the tail diminishes regularly in diameter, but presents 2 swellings in the posterior part.

Found among algae, in the Rhone River, Switzerland. This species is said to resemble *M. macrostoma* Bastian in the form of the buccal cavity, but to differ from that species in the details of the structure of the mouth, as well as in the form and length of the tail. Fig. 24, after Stefanski.



11. *M. major* Cobb. Labial papillæ of the inner row each with 3 (?) nerve-endings. Amphids slightly farther forward than the apex of the dorsal tooth, small. Lateral fields one-fifth as wide as the body. Intestine composed of rather



1.8	8.	19.	55.25	95.	
1.6	2.2	2.6	2.9	1.5	→ 3.4 mm
1.5	6.6	19.	55	95.	
1.6	2.3	2.9	2.8	2.3	→ 3.4 mm

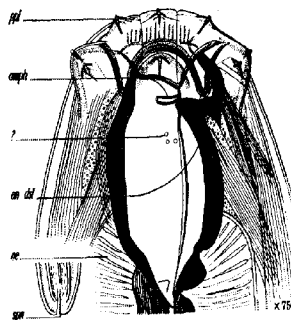
showing an indistinct tessellation. The eggs are probably less than twice as long as wide. Each of the 12 rather conspicuous, echinulate, mammiform accessory organs is situated on the posterior side of a transverse ceratinous ridge extending one-fourth the distance around the body. The anterior two or three and the posterior one of these organs are smaller than the others. There are 2 pairs of ventrally submedian papillæ, also innervated, on the anterior third of the tail, the posterior pair being near the end of the anterior third, and the other pair half way between that point and the anus. There are other papillæ faintly visible on the dorsal side of the tail and elsewhere (fig. 16). The females of this species also present papillæ near the vulva: 3 small, ventrally submedian papillæ on each side of the body, one opposite the vulva, one a short distance in front of it and another a short distance behind it, and in addition a tandem series of 3 papillæ, both in front of and behind the vulva, on the ventral line. The location and conformation of these papillæ is shown in figure 12. Doubtless the females of other species possess similar papillæ. Fixed with osmic acid; examined in water.

Found about the roots of plants, in damp soil, Moss Vale, New South Wales, Australia. Also about turnips in Tasmania. This species resembles the following. Fig. 25.

12. *M. gerlachei* de Man. Lateral fields about one-third as wide as the body. In transverse section the buccal cavity, though nearly round, is obscurely three-sided, and shows the existence of 3 small, longitudinal grooves in the wall of the

2.	5.2	18.	50.33	92.5	
1.8	?	?	3.7	2.	3.7 mm
2.	5.6	20.	55.5	95.5	
1.8	?	?	3.7	2.3	3.2 mm

pharynx, presumably so functioning as to increase the elasticity and mobility of the pharyngeal walls. What appears to be a renette pore occurs immediately behind the nerve-ring. Anal muscles are well developed in the female. Spicula arcuate, tapering both ways, about one and one-third times as long as the anal body-diameter, and in their widest part about one-sixth as wide as the corresponding portion of the body. The accessory pieces are about one-third as long as the spicula, relatively small and poorly developed, appearing to be parallel to them when viewed in profile. The



pre-anal ventral row of supplementary organs is essentially the same as in *major* (fig. 16). According to Steiner's observations the number of supplementary organs in this species may at times be as great as that noted in *major*. Steiner calls attention to the existence of a submedian row of pre-anal papillæ, lying on either side of the ventral row. The tail bears 3 pairs of papillæ, one submedian or subventral pair near the anus; a second subventral pair slightly behind the middle; and a third dorsally submedian pair at the beginning of the final fourth of the tail. In the male the slightly conoid spinneret is one-sixth to one-seventh as wide as the base of the arcuate tail. The proportions are about the same as in the female, although the tail of the female is slightly longer and more slender, and not so strongly arcuate.

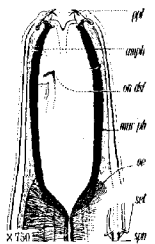
Found among fresh water algæ, Cape Van Beneden, Danco Land. It is rather difficult to point out satisfactory differences between this species and *major*. The pharynx of *gerlachei* is relatively smaller and is thicker walled, and its dorsal tooth is slightly farther forward. The number of labial papillæ—sixteen—appears to be the same in each. The amphids are perhaps slightly farther back in *major* than in *gerlachei*. The number of papillæ noted on the tail of the male of *major* is greater than that noted on the tail of *gerlachei*, but so far as the distribution of the dorsal papillæ on the tail of *gerlachei* is concerned, they appear to accord very closely with those of *major*. The two species appear to be closely related. Fig. 26 on the previous page (after de Man).

13. *M. fovearum* (Dujardin) Bastian. This is an insufficiently known species and may have to be declared *nomen nudum*. Head a trifle angular. Pharynx angular, "armed with 2 to 3 straight pieces, each ? ? 16. +50! 83. 2.5 r- (?) with a pronounced tooth in front of the ? - ? ? 3. ?

Tail tapering at first but retaining the same diameter through its posterior half, and ending in a sort of spinneret (?). Eggs in single series.

Found at Rennes, France, in a fresh water ditch, along with *Branchipus*, *entomostrica*, *Englena* etc. De Man suggests that this species is related to *tridentatus*.

14. *M. megalainus*, n. sp. Labial papillæ obscure. Amphids obscure, half way between the apex of the dorsal tooth and the anterior extremity. Cardia large and conspicuous, more or less cylindroid, three-fourths as wide as the body. Intestine about 12 cells in girth, more or less distinctly tessellated. At the end of the anterior third the tail is one-fourth as wide as at the anus. Spinneret slightly swollen, with 2 very small digitate setæ.



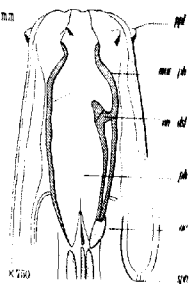
About the roots of plants, in a tamarack swamp, Wisconsin, U. S. A. This monoch is peculiar in the relatively meager development of the labial papillæ and the pharyngeal teeth, and the weakness of the pharyngeal muscles. Flemming solution to glycerine. Fig. 27.

15. *M. macrostoma* Bastian. Inner set of labial papillæ inconspicuous; outer set fairly well developed. The neck tapers but little. The head, however, is rather markedly convex-conoid. De Man describes and figures 2 exceedingly minute submedian teeth at the base of the pharynx. Oesophageal lining strongly developed. Intestine 12 to 15 cells in girth, tessellated. Posterior half or two-thirds of the tail of the female of practically uniform diameter, tapering but very slightly. Spicula arcuate, very slender, about twice as long as the anal body-diameter. Their proximal ends are not cephalated. They are accompanied by 2 accessory pieces, hardly one-third as long, arranged parallel to their distal parts. Supplementary organs, about 20, in the form of innervated papillæ, spread over a distance nearly

equal to the length of the tail, the posterior member of the series being a short distance in front of the anus. There are 3 pairs of somewhat equidistant subventral post-anal papillae on the anterior part of the tail. There are also lateral papillae on the tail.

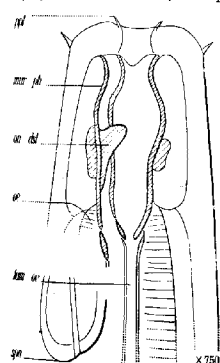
This beautiful, active, rather common species is found in

the soils of meadows and marshes in many parts of Europe; it is also aquatic. The writer has followed Dr. de Man's rehabilitation of Bastian's *macrostoma*. Corresponding females which the writer has found at the Arlington Farm, Virginia, S. A., indicate the presence of exceedingly fine transverse striae, and of inconspicuous wings. Amphids obscure, just behind the lips, difficult to see except in dorso-ventral view. The oesophagus receives the basal fourth of the pharynx, and in this region is very slightly swollen. The writer failed to see the minute basal onchi mentioned by de Man. The thin-shelled eggs, which occur in the uteri one at a time, are about one and one-fourth times as long as the body is wide and about half as wide as long, and are apparently deposited before segmentation begins. The writer has no doubt this species is syngonic. A female which had yet to undergo the final moult contained an egg which had its shell completely formed, and was evidently in a state preparatory to segmentation. Flemming solution to glycerine. Fig. 28 (after de Man).



According to Bastian the following differences exist between *macrostoma* and *truncatus*; *macrostoma* is 50 per cent longer, and is relatively narrower in the ratio of 3.5 to 5.3. *Macrostoma* tapers less in the neck, and has papillae, while *truncatus* has none. While *macrostoma* is the larger, its pharynx is no longer; the onchus is a little farther forward. The intestine in *macrostoma* is less distinctly tessellated. The posterior part of the oesophagus in *macrostoma* is figured as having an internal expansion. These characters seem to the writer sufficient to separate the two species. It is probable that papillae on the head of *truncatus* were overlooked by Bastian. This would have been easy, for instance, if the papillae on *truncatus* are similar to those on *megalaimus*. See figure 27.

16. *M. obtusus*, n. sp. Papillae setose. The adjacent figure (29) is after



Butschli, whose figures seem to represent a different species from that figured by de Man under the name *macrostoma*, notwithstanding the general resemblances. The proportions of the tail and of the spicula are different in the two forms; the distribution of the papillae on the tail is also different, and, while the number and position of the pre-anal ventral supplementary organs are about the same, their form as shown by Butschli is decidedly different from that shown by de Man. In addition, Butschli's figure shows 3 pairs of pre-anal, ventrally submedian papillae coextensive with the ventral row. Butschli's data may therefore, the writer thinks, be taken as establishing this new species. Synonym, *M. truncatus* Bastian of Butschli.

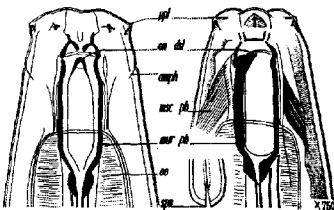
Found in the River Main, Germany; common in mud and in aquaria and among aquatic plants, in moving water not foul. See also fig. 15.



17. *M. tunbridgensis* Bastian. The Tunbridge mononch is interesting historically as well as intrinsically, for it was an examination of numerous specimens of this aquatic nema that marked the beginning of the classical researches of the

2.4	6.7	24.	52.20	89.	→	1.8 mm
2.1	2.8	3.6	3.7	2.3		
2.4	7.8	23.	53.24	90.	→	1.3 mm
2.	2.5	2.6	2.7	1.7		

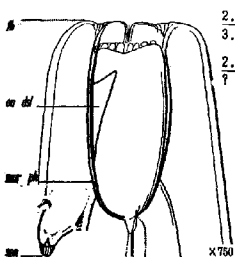
well-known English nematologist, H. Charlton Bastian. The upper formula is the average of glycerine specimens from the Arlington Farm, Virginia, U. S. A., while the lower formula is the average of the writer's balsam specimens from Tunbridge Wells, Eng-



land. As a rule the head is rather suddenly contracted opposite the pharynx, and this is perhaps the best distinguishing mark of the species. Bastian, who had an abundance of specimens, emphasizes this character. The adjacent figures are those of Dr. de Man, and show the pharynx relatively a little narrower than is usual. The tails of the writer's Tunbridge Wells specimens accord rather with Bastian's figure than with his description. As is often the case in other mononchs, the labial papillae stain more strongly with carmine than do adjacent tissues, so that the lip region as a whole appears strongly colored. Opposite the dorsal tooth there is an exceedingly minute, low, subventral projection. The form of the amphids is not fully determined; they are located nearly opposite the base of the pharyngeal tooth, and have a width one-half to one-third as great as that of the pharyngeal cavity. Near the cardia the oesophageal lining occupies about one-fourth of the optical longitudinal section of the oesophagus. The intestine, which may present a certain amount of tessellation, is about 10 to 12 cells in girth. The anterior two-fifths to one-half of the tail is conoid in such a fashion that at the middle the diameter is about one-sixth as great as at the anus. Thence onward the tail is nearly cylindrical, and ends in a very slightly expanded terminus armed with one or two very inconspicuous papillae. That a sticky substance often exists on the surface of the terminus of the tail is evident from the accumulation there of minute particles of foreign matter. Caudal glands appear to exist immediately behind the anus, but their nuclei have not been definitely made out as yet. The lateral fields appear to be one-third as wide as the body. Each ovary contains a score or more of developing ova, arranged in several tiers in the distal half of the organ, but single file elsewhere. The somewhat elongated eggs are about one and one-third times as long as the body is wide, and about half as wide as long, and occur in the uteri one at a time.

This seems to be primarily an aquatic species, though the writer has found it also in soil in the vicinity of rivers and streams. Fig. 30 (after de Man).

18. *M. truncatus* Bastian. Oesophagus conoid, its lining well developed. Intes-



2.5	?	25.	50.4	86.	→	1.8 mm
3.	?	5.	5.3	3.4		
2.5	?	25.	50.4	92.	→	2. mm
?	?	?	?	?		

tine about 12 cells in girth, more or less distinctly tessellated. Lateral fields broad and distinct. It is a question whether to retain this species on the basis of Bastian's original description, or to accept Bütschli's description as a rehabilitation of Bastian's species. It is hardly likely that any species of *Mononchus* is destitute of labial papillae, and in this respect Bastian's description seems defective. The extreme reduction of the

labial papillae so far recorded is shown in *megalaimus*. Bütschli and later authors describe and figure the papillae of *truncatus* as setose. It seems hardly likely that Bastian would have overlooked setose papillae such as those figured by Bütschli. In that case Bastian's *truncatus* should be retained as a species, probably having very inconspicuous labial papillae similar to those of *megalaimus*, while the data given by Bütschli may be taken as establishing a new species, for which the name *obtusus* is proposed. (See No. 16.)

Found in a small pool, among decaying moss and liverwort, England. Fig. 31 (after Bastian).

19. *M. dadayi* Micoletzky. A striking character of this species, "*M. macrostoma* Bastian var. *armatus* Daday," as described by its author, is the presence of 6 small,

tooth-like cuticular spines close around the mouth. No such structures have been seen in other species, and accordingly Micoletzky has proposed for the form the name *dadayi*.

This is a littoral species. The description and drawings rest upon the examination of a single specimen. The original description is very brief and the accompanying illustrations, one of which is here reproduced, are meager sketches of the head and tail ends. A more complete examination of further specimens is desirable. Fig. 32 (after Daday).

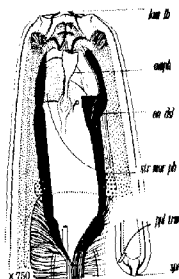
20. *M. longicaudatus* Cobb. Opposite the apex of the dorsal tooth there are refractive transverse thickenings of the wall of the pharynx in the ventrally submedian region, and in front of these thickenings there are a few transverse striae. The lateral fields are two-fifths as wide as the body, and are distinctly to be seen, since they have definite lateral contours, doubtless owing to the thickness of the muscular layer. The lateral fields contain scattered, nearly colorless granules somewhat smaller than those contained in the intestinal cells. In young specimens the vagina is distinctly separated from the uterus by a deep constriction, and the uterus itself is bulbous near this constriction and narrower farther away. *Longicaudatus* is a syn-  

3.	6.7	28.	55+23	88.	
In	2.	2.4	3.	3.	2.4

 gonistic species. In the adult and egg-producing specimens the eggs are seldom or never seen more than two at a time, one in each uterus.

A predaceous species, feeding upon other nematodes, upon rotifers and protozoa. It is cosmopolitan, and is found in rivers, ditches and pools, as well as in the soils of swamps and meadows. It occurs, sometimes in vast numbers, in the sand of the slow filter beds of the water-works of cities and towns. Flemming solution to glycerine. Fig. 33; also fig. 2, p 434.

*Longicaudatus* suffers from an internal disease caused by a fungus having a branched mycelium. The width of the mycelium is about half as great as the thickness of the body wall of the nema, and the septa of the cells are separated from each other by a distance equal to the diameter of the body. There are two other diseases affecting this nema, one of microbe origin, the other of fungous origin; they appear, however, to be confined to the cuticle. One consists of short-styled, elongated-ellipsoidal elements on the surface of the body extending outward at right angles. These have been seen on the tail end. The microbe growth appears as a coating, sometimes of considerable thickness, and occurs on various parts of the body. It has been seen

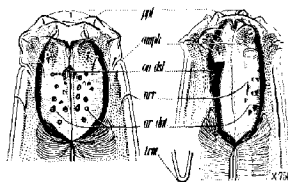


at both extremities. The adjacent figure (34) depicts the tail end of a male found in Hawaii about the roots of sugar-cane. The general resemblance to the male assigned by Bütschli to *M. truncatus* Bastian is very striking, yet the differences in detail are also pronounced. The number of supplementary organs is 16 instead of about 20, and the organs themselves relatively shorter and more plump. The spicula and their accessory pieces have the same general proportions and size. The tail also has the same form and proportions, but the terminal portion is more slender in the Hawaiian specimen, and the distribution of the papillae thereon is decidedly different, as will be seen by comparing figures 15 and 34. Male mononchs are so rare that the amount of variation that may exist in a given species is a nearly unknown quantity, so that it is not exactly easy to make intelligent comparisons between the males in these two cases. The Hawaiian male is supposed to be the male of *M. longicaudatus*, the only one that has ever been seen. It is interesting to note that when the spicula become long and slender the accessory pieces also become long and slender, but maintain their general form and are bifurcated at the distal end. Fig. 33 (on the previous page) and fig. 34. It is a curious fact that this, the only male of *M. longicaudatus* ever seen among the many thousands examined, should have come from soil, since *longicaudatus* is much less common in soil than in water.

21a. *M. dentatus*, n. sp. This representative of a new subgenus is especially interesting as a guide to speculation concerning the relationship of *Mononchus* to

3.	2.	27.	62.14	95.	
2.6	2.6	3.3	3.3	1.9	1.1 mm

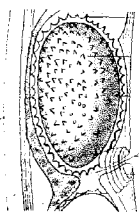
other genera. The scattered denticles are paralleled in certain marine nemas. The arcuate tail is conoid from the raised anus. The rather blunt terminus is about one-fourth as wide as the base of the tail. There is a pair of ventrally submedian, innervated papillae a little in front of the middle of the tail. The amphid is sometimes more elongated than shown in the illustrations.



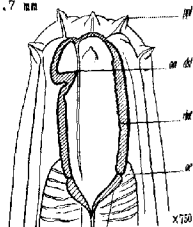
Description of a young female, from roots of orange trees, Bahia, Brazil. Fig. 35. For 21b, *M. recessus*, and 21c, *M. decurrens*, see Appendix.

22. *M. punctatus*, n. sp. This species is proposed for the reception of the specimen described by Brakenhoff under the name *M. papillatus* Bastian, which appears to differ from

2.8	?	25.	85.28	93.	
2.2	?	?	3.5	?	1.7 mm



described in that the shells of the eggs are echinulate. It is placed in the subgenus *Prionchulus*, though with some doubt, principally because both the description and the figure of Brakenhoff show the presence of denticles on the ventral rib of the pharynx. The author says: "Hier findet sich

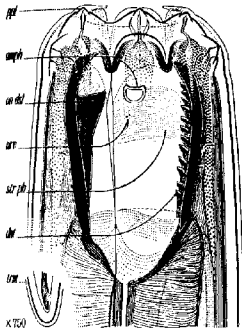


nämlich eine, in der Mitte (und an den 2 Seiten) fein gezähnelte Leiste. Diese

Zählung erstreckt sich über eine etwa 0.016 mm. lange Strecke und beginnt distalwärts etwa in der Höhe der Spitze des dorsalen Zahns." The ellipsoidal eggs occur in the uteri one at a time, are about as long as the body is wide, and two-thirds as wide as long.

Found among the roots of *Alopecurus denticulatus*, as well as aquatic habitats, in the bottom of ditches and lakes in Germany, Fig. 36 and 36a (after Brakenhoff).

23. *M. muscorum* (Dujardin) Bastian. The oldest, and one of the best known species. Intestine tessellated. Tail conoid and arcuate. The reflexed ovaries, each containing about a dozen ova arranged more or less in single file, extend half way



2.	9.	24.	465	32	84.	
2.1	2.7	3.2	3.6	1.6	2.5-3. mm	

back to the projecting vulva. The eggs are one and one-half times as long as the body is wide and three-fourths as wide as long. The anterior sexual organ is somewhat the larger. Fig. 37, left.

This is a beautiful and rather common cosmopolitan species, occurring in swamps, marshes, meadows and moorlands. It has been found in various parts of Europe and is not uncommon in the United States. It was first found by Dujardin in the Jardin des Plantes, Paris, where it still thrives; the writer recently found it about the roots of some heather imported thence. It feeds on smaller animal organisms, among them other nematodes. The following is a variety:

*M. muscorum* (Dujardin) Bastian *macrolaimus*, n. var. Besides differing slightly in proportions from the type form of the species, the variety has a somewhat larger pharynx; with smaller denticles on the ventral rib. The submedian papillae of the outer sets are apparently double instead of triple, though at some distance behind the outer submedian papillae there is a special submedian innervation. Most of these minor differences are set forth in figures 36 and 37.

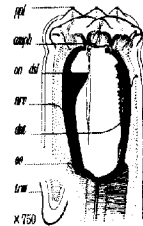
Found in *Cladonia rangiferina*, tamarack swamp, Wisconsin, U. S. A. Fig. 38, right.

24. *M. longicollis*, n. sp. A species resembling *M. muscorum*, but which differs in the proportions of the various parts and in the conformation of

the pharynx, the denticles of which are irregular and inward pointing. Submedian papillae of the outer row double, instead of triple as in *muscorum*.



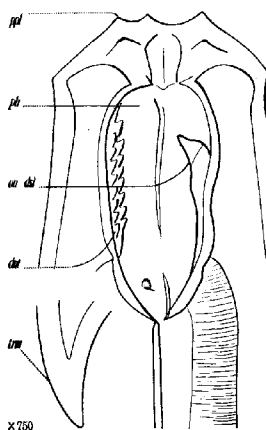
2.3	7.4	24.	460	25	82.	
2.	3.2	3.7	4.4	2.5	1.9 mm	



Amphids relatively

larger than in *muscorum*. Striae very difficult of resolution. Found about the roots of pitcher-plants and tamarack, in a swamp, Wisconsin, U. S. A. The difference between this and *muscorum* may not be very important. Both are nematodorous. Flemming mixture to glycerine. Fig 39 (at bottom previous page).

25. *M. spectabilis* Ditlevsen. The muscular oesophagus encompasses the proximal third of the pharynx, and has a conspicuous lining. The uteri may contain



?	?	20.	55	98.8	4. mm
?	?	?	?	?	?
?	?	20.	M	?	3.6 mm
?	?	?	?	?	?

from 2 to 4 eggs,  
usually 2. The  
acute conical tail  
is strongly arcu-

ate. The male is a little more slender than the female, and increases in size from a point where the supplementary organs commence, in such a way that the body assumes a maximum circumference near the anus. The copulatory muscles are strongly developed, and the numerous, prominent, supplementary organs appear to have a subventral position, forming two longitudinal rows, between which is a groove. Fourteen of these supplementary organs are figured by Ditlevsen—manifestly not the whole series. The arcuate spicula, which have a strengthening piece in their distal halves, are about one and one-half times as long as the anal body-diameter. Their proximal ends are not cephalated. At the widest part, toward

the proximal end, they are about one-fifth to one-sixth as wide as the body; thence toward the distal end they taper gently. The obscurely bifurcated accessory pieces, which in profile view appear to cross the spicula, are of the usual form, and are about one-third as long as the spicula, and about one-third to one-fourth as wide as long. Their distal extremities lie somewhat in front of the tips of the spicula and toward the ventral side of the body. The elongated eggs are nearly one and one-half times as long as the body is wide, and less than half as wide as long.

Numerous specimens, the males as numerous as the females, found at Hellerup, near Oresund, Denmark. This species exhibits the phenomenon of flotation. Ditlevsen says: "If some material (meadow soil) is spread in a flat glass cup and water is poured over it, the mononchus will mount rapidly and be lying on the surface dry and shining." Fig. 40 (after Ditlevsen).

26. *M. index* Cobb. No striae seen. The neck diminishes opposite the base of the pharynx to form a rather cylindrical, truncated head which is slightly expanded at the lip region. Amphids, one-fifth as wide as the head, are indicated by transverse markings, bent backward at each end, and located opposite the middle of the dorsal tooth. Denticles in about five rows, the outer rows more distinct. Pharynx half as wide as the head, and about three times as deep as wide. Oesophagus more or less conoid, with a massive lining occupying about one fourth of the optical section. Cardia pointed. Intestine few cells in girth; rather obscurely tessellated. Rectum half as long as the anal body-diameter. Longitudinal fields are visible throughout most of the length, and are about two-fifths as wide as the body. The diameter of the body increases somewhat just in front of the anus, and then diminishes suddenly at the anus, so that the beginning of the tail is very considerably less in diameter than the portion of the body immediately in front of the anus.

The diameter of the cylindrical portion of the tail is about one-fourth that of the body at the anus. Caudal glands 3, egg-shaped, opposite the anus. Spinneret slightly apiculate and apparently unarmed. The eggs are evidently of large size. A single egg, not yet passed on to the uterus, was four-fifths to five-sixths as wide as the body, and about three times as long as wide.

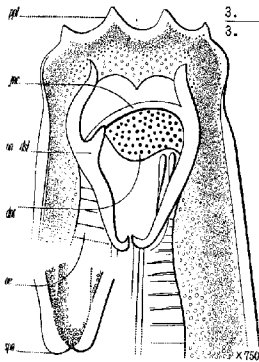
Common about the roots of sugar cane on various plantations on the island of Hawaii. Flemming solution to glycerine.

27. *M. reversus*, n. sp. This very interesting abnormal form possesses striae that appear resolvable into rows of dots. Intestine about 6 cells in girth, faintly tessellated. Tail more or less cylindroid in the posterior half, its terminus one-fourth to one-fifth as wide as its base. Lateral fields two-fifths as wide as the body. The eggs are of relatively large size, since an ovum not yet passed on to the uterus is 5 to 6 times as long as the body is wide. It is therefore likely that the eggs occur in the uterus only one at a time. The relatively broad ovary tapers but little; it contains about a dozen developing ova.



Rio Janiero, Brazil, about the roots of *Platonia insignis* Mart. In general this species resembles *incurvus* and *minor*, but is readily distinguishable by the form of the sexual organ, and by the sparseness of the pharyngeal denticles, only a few of which are to be seen. When the female sexual organs reduce to one, this remaining one usually extends forward from the vulva. Here the reverse is the case; hence the specific name. Flemming solution to glycerine. Fig. 41.

28. *M. obtusicaudatus* Daday. Tail conoid, slightly arcuate; toward the end rather suddenly diminished in size. The spinneret well marked.



Found at Berlinhaven, Island of Salao, New Guinea, in fresh water. It seems probable from Daday's description that there are 3 teeth in the pharynx, 1 dorsal and 2 smaller submedian ones just at the base of the rasps. Probably the junction between the posterior and anterior elements of the pharyngeal walls is unusually prominent; this would account for the "bogige leiste" mentioned in the original description and shown in the original figure along the anterior margin of the rasp. Fig. 42 (after Daday). Assuming Daday's drawing to be more or less conventionalized, this species might be regarded as identical with *minor*.

29. **M. brachyuris** Bütschli. Amphids appear as transverse slits opposite the onchus. Lining of the œsophagus strongly developed. Cardia plainly to be seen.

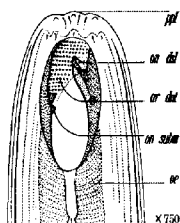
Intestine tessellated.  $\frac{2.2}{2.4} \frac{8}{2.9} \frac{28}{3.6} \frac{62.18}{3.9} \frac{96}{2.2} \rightarrow 1.2-2. \text{ mm}$   
Rectum half as long  
as the anal body-diameter. Caudal glands more or less  
saccate, opposite the somewhat raised anus. Tail some-  
what arcuate. Spinneret pore a little to the dorsal side of  
the middle of the terminus. The vulva is a conspicuous  
feature, owing to the thickness of the walls of the vagina,  
which is one-half as long as the body-diameter. Series of



male supplementary organs, according to de Man, about 12, mammiform and apparently protrudable except the two anterior and the posterior, which are more or less rudimentary. Series about twice as long as the tail.

A cosmopolitan species. In Florida, the writer found this species feeding on the larvæ of *Heterodera radicola*, an extremely serious root pest. Fig. 43, bottom p. 467.

30. *M. denticulatus*, n. sp. Onchus opposed by two small subventral onchi farther back, the left a little farther forward than the right.



Found in the Zambezi River, South Africa, among fresh water algæ. The peculiar form of the head and pharynx, and the unusually large number of denticles are the prominent characters of this species. Only a single mutilated specimen has been seen by Dr. Micoletzky. As it is unlikely that the large number of denticles shown in the original figures can be due to moulting phenomena, it would seem that this form differs distinctly from all others. Fig. 44 (after Micoletzky). As neither Micoletzky's text nor figure suggests moulting, the numerous rows of denticles are assumed to be normal.

31. *M. sparsus*, n. sp. Each rasp consisting of but 2 rows of denticles. The tail diminishes suddenly in size behind the elevated anus, and tapers somewhat in the posterior three-fourths. The terminus is about one-fourth as wide as the base of the tail. The caudal glands (?) lie opposite the rectum.

Found in sphagnum from greenhouses, Department of Agriculture, Washington, D. C., U. S. A. Flemming solution to glycerine. Fig. 45.

32. *M. micrurus*, n. sp. This odd form appears to have no submedian onchi. Rasps of only about four rows of denticles. Amphids not seen. Lining of the œsophagus well-developed, occupying three-fifths of the optical longitudinal section.

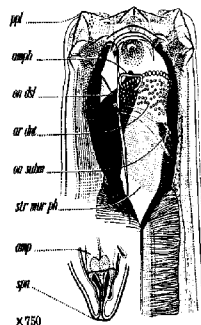


3. 12. 33. 98.  
2.7 3.4 3.7 3. 2.2 → .8 mm

Intestine about 5 cells in girth, not tessellated, or only faintly so. Tail very short and strongly arcuate or bent. Spinneret about one-fifth as wide as the base of the tail. Rectum somewhat shorter than the anal body-diameter; longer than the tail. Caudal glands not clearly seen, probably opposite the rectum. Ampullæ of the caudal glands not very strongly developed.

Described from young specimens found about Litchi roots, Fukien, China. Resembles *breviceaudatus*. Characterized by the extremely small and very strongly arcuate tail. The spinneret is sometimes turned nearly at right angles to the axis of the tail. Flemming solution to glycerine. Fig. 46.

33. *M. incurvus*, n. sp. Striæ resolvable with difficulty and into rows of dots. Dorsal onchus opposed by 2 inconspicuous, ventrally submedian onchi of smaller size opposite its base. The lining of the œsophagus is a prominent feature, occupying about two-thirds of the apparent width of the œsophagus. Intestine 12 to 15 cells in girth, not tessellated, its granules numerous and fine. Caudal glands 3, broadly saccate, opposite the anus, their ampullæ long and filling the posterior part of the tail.



There is a flattish cardia. Anus raised. Longitudinal fields two-fifths to one-third as wide as the body. From the more or less elevated vulva the vagina leads inward at right angles to the ventral surface one-third the distance across the body. The eggs are one and one-half times as long as the body is wide, and occur one at a time in each uterus. The ovaries contain about a dozen developing ova.

Sandy soil in a cranberry bog, Arlington Farm, Virginia, U. S. A. Also on the margin of the spring that gives rise to Salt River, Jamaica. Flemming solution to glycerine. Fig. 47 (at bottom of previous page).

34. *M. sigmaturus*, n. sp. Two very inconspicuous submedian onchi are found opposite the base of the dorsal onchus, just at the base of the rasps. Intestine 10 cells in girth, comparatively distinctly tessellated. The rectum is about as long as the anal body-diam-

eter, and is some-

what sigmoid. The anus is very distinctly visible on account of its contour, and on account of the refractive nature of the lining of the rectum. What appears to be a renette pore exists immediately behind the nerve-ring. The distinct lateral fields are about one-fourth as wide as the body, and are characterized by the presence in them of scattered granules much smaller in size than those of the intestine. The posterior part of the tail is

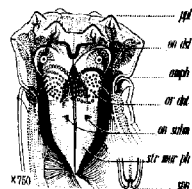
somewhat digitate, and the whole is slightly sigmoid. From the anus the tail tapers rapidly to near the middle, so that if the posterior half were lacking the tail would be rounded. The diameter of the tail at the middle is about one-third as great as at the base. From the middle onward the tail for a short distance is of uniform diameter, and then tapers rather rapidly in the posterior fourth to a rounded or subtruncated spinneret. Small, somewhat finger-shaped setae are found on the tail; one dorsally sublateral pair, a trifle in front of the anus; another dorsally sublateral pair near the middle of the tail but located on the more bulky part; finally, a third ventrally sublateral pair a little in front of the digitoid part of the tail. The caudal glands are opposite the rectum. The eggs are about two and one-half times as long as the body is wide. The tapering ovaries contain 10 to 12 developing ova, arranged irregularly.

Found in various parts of the United States and Mexico. Resembles *minor* and *brachyuris*, from which it may be distinguished by the form and structure of the tail. Flemming solution to glycerine. Fig. 48.

35. *M. tenuis*, n. sp. Wall and dorsal tooth of the pharynx rather strongly developed. When the lips are closed the pharynx is hardly half as wide as long. Dorsal tooth slightly arcuate, its point located close to the base of the lips. The

submedian teeth are easily confused with the denticles. Lining of the oesophagus well developed, occupying one-fourth of the longitudinal optical section. There is a small conoid cardia. Intestine probably about 6 cells in girth, not definitely tessellated. Anus raised and conspicuous, the anterior lip somewhat massive and overhanging.

The arcuate, conoid tail ends in a spinneret one-fifth to one-sixth as wide as its base. The ovaries, of which the posterior is somewhat the smaller, appear to contain about a dozen ova. Inconspicuous papillae appear on the ventral side of the female near the vulva. Two were noted behind the vulva and one or more in



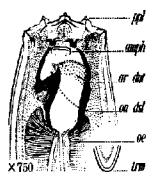
1.5	5.6	26.	72.22	97.
1.4	1.7	2.1	2.3	1.3
1.5	5.2	25.	42	97.
1.5	1.8	2.1	2.2	1.8

1.9 mm  
1.9 mm



front of it. The tail of the male is somewhat like that of the female but diminishes very suddenly behind the anus. Five pairs of innervated papillæ have been seen on the tail of the male, two of them, however, exceedingly inconspicuous and easily overlooked: Of the three more conspicuous, one ventrally submedian pair is located a short distance behind the anus; a second dorsally sublateral pair occurs a little behind the middle of the tail, and a third subventral pair occurs a short distance in front of the spinneret. Of the two more inconspicuous pairs, one is nearer the spinneret than that just mentioned, and the other, lateral, and slightly behind the middle of the tail. The arcuate spicula are about one and one-fourth times as long as the anal body-diameter. At their widest part, near the middle, they are about one-fifth to one-sixth as wide as the corresponding part of the body and thence taper in both directions; they are not cephalated. The distal ends are obscurely two-pronged. The obscurely bifurcated accessory pieces are of typical form and size, about one-third as long as the spicula and about one-fourth as wide as long. Fourteen rather closely approximated, equidistant supplementary organs occur in front of the anus, occupying a distance about three times as great as the length of the tail. Internally the organs seem to be short, broad tubes of slightly varying diameter; these are probably slightly protrudable. The protrudable portion is not hispid as is the case in *M. major*;—on the contrary, it appears to be smooth. The anterior one and the posterior three of these organs are not so well developed as the others, that near the anus being reduced to a mere innervation; the distance between this latter and its nearest neighbor is about twice as great as between any other adjacent members of the series. These organs give to the ventral contour a crenate or serrate appearance. The anal muscles are prominently developed. The ejaculatory duct is often filled with elongated spermatozoa, somewhat resembling those of *Dorylaimus*, and similar in form to those figured by Dr. de Man for *M. gerlachei*. Each one may be one-fourth as long as the body is wide, or thereabouts. There are two outstretched testes. The blind end of the anterior is about as far behind the base of the neck as the latter is behind the anterior extremity. The blind end of the posterior seems to lie about twice as far in front of the foremost supplementary organ as this latter is in front of the anus. The spicula have a median stiffening piece, and their proximal ends lie toward the dorsal side of the body.

Found about the roots of plants on the Arlington Farm, Virginia, U. S. A. Resembles *M. minor*, but in the proportions of the pharynx there are notable differences. The walls are here thicker; the amphids are larger and farther back; the lips and onchus are strongly developed, so that when the pharynx is closed the cavity appears smaller than in *minor*. Opposite the anterior supplementary organ there is a fibrous ring, probably nervous. A similar structure has been noted in other species. There probably exist at this point in the body special nerve commissures. Flemming solution to glycerine. Fig. 49 (near bottom of previous page).



36. *M. similis*, n. sp. Striæ of the cuticle more or less easy of resolution. Lining of the œsophagus strongly developed, occupying three-fifths of the longitudinal optical section. 3. 10. 34. Y 98. 3.1 3.6 4. 3.8 2.6 .8 mm

Anus slightly elevated, especially the anterior lip. The scattered granules in the cells of the intestine are small, but variable in size, and do not give rise to tessellation. The more or less arcuate tail is conoid to the blunt terminus, which is about one-fourth as wide as the base of the tail. A ventrally sublateral innervated papilla occurs on each side near the middle of the tail. There are no caudal glands. Description derived from a single young female.

37. *M. obliquus*, n. sp. Two small, ventrally submedian onchi present, opposite the base of the dorsal onchus. (Esophagus at first a little swollen; its lining well

38. *M. lacustris* Cobb. The amphids have the form of "slits," 3 to 4 times as long as wide, and are placed at the base of the lips nearly opposite the apex of the dorsal onchus. They

Found in fresh water lakes, Michigan, U. S. A.; about the roots of ferns, Panama Canal Zone; and in the Silver Springs, Florida. Resembles *M. brachyuris* Bütschli, from which it differs in the form of the tail and spinneret. *M. polonicus* Stefanski seems to closely resemble this species. Sublimate to balsam. Fig. 52.

39. *M. polonicus* Stefanski. Two minute teeth are found at the base of the buccal cavity. The conoid tail is somewhat arcuate from the raised anus, and ends in a truncated spinneret one-fourth as wide as its base. The three caudal glands are located in a tandem series in the anterior third of the tail.

Description derived from young specimens found in vegetable detritus in the Czarna River, Poland. Said by its author to resemble the next species, No. 40.

40. *M. minor* Cobb. There are 2 minute, submedian onchi, easily overlooked. Amphids, only one-sixth as wide as the corresponding portion of the head, are

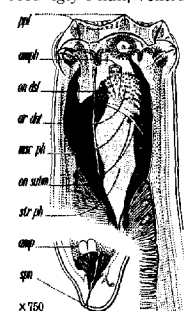
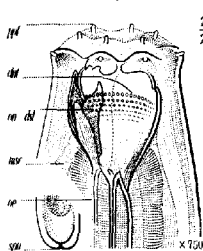
present opposite the apex of the dorsal tooth, and consist of arcuate, refractive markings having their convex side toward the lips. They appear to be about one-fourth as wide as the corresponding portion of the head. There are excessively minute striæ or dentations of the inner surface of the margins of the lips; these structures are so fine that they might easily escape observation—much finer than the rasp-like teeth of the pharynx. The lining of the œsophagus occupies nearly one-third of the optical longitudinal section. The cells of the intestine contain small, somewhat uniform rather evenly distributed granules. The anus is slightly raised, the anterior lip being a little more pronounced than the posterior. The conoid tail is rather strongly arcuate, or even more or less bent near the middle. The comparatively well developed spinneret is one-third as wide as the base of the tail, and possesses a valve similar to that found in *Mononchulus*. The caudal glands are located opposite to, or a little behind the rectum. The lateral fields are two-fifths as wide as the body.

This is a cosmopolitan species, found in tropical and temperate regions. It closely resembles *M. brachyuris* of Bütschli, but is smaller and differs somewhat both in the structure of the tail and in that of the pharynx. Osmic acid to water. Fig. 53.

41. *M. brevicaudatus*, n. sp. Walls of the pharynx unusually thick. Two exceedingly small, ventrally submedian onchi, opposite the middle of the dorsal onchus.

Lining of the œsophagus prominent, occupying one-third of the optical section. Intestine 6 to 8 cells in girth, faintly tessellated. Contour of the tail like that of the head of a duck whose beak is very short; from the anus onward having roughly an equilateral contour. Spinneret more elaborate than usual. The ceratinized walls of the vagina are plainly visible. The elongated eggs are two to two and one-half times as long as the body is wide. The ovaries taper but little. About a dozen females have been examined. No males have been seen. Sperm has been seen at the flexure in the ovaries. The species is probably syngonic.

Found about the roots of plants in a cranberry bog, New Jersey, U. S. A. Resembles *micrurus* and *brachyuris* in its general form, but differs in the details of the pharynx and in those of the tail. The species is nematovorous, and also feeds upon rotifers. Sublimate to balsam. Fig. 54, in which, as in many of the original illustrations used in this chapter, what at first sight appear to be merely lines used as shading, are in reality carefully charted striæ or laminations of the wall of the pharynx.



42. *M. japonicus*, n. sp. The head is not set off in any marked fashion. Amphids present in the form of elliptical markings nearly opposite the apex of the single dorsal tooth; the length of their long axes, which are placed transversely on the head, is probably about one-sixth as great as that of the diameter of the head. The capacious pharynx is somewhat deeper than the head is wide; the anterior portion has a diameter more than half as great as that of the corresponding portion of the head, while the posterior portion has a diameter about two-fifths as great as that of the base of the head. The single, highly refractive dorsal tooth has its apex somewhat in front of the middle of the pharynx. The rasps consist of 5 to 6 rows of teeth, forming a group whose width is about one-fifth as great as the depth of the pharynx. The wall of the pharynx is strongly developed, and is very finely transversely striated in the posterior part. The lining of the œsophagus is an exceedingly distinct feature throughout its length, and appears to occupy about one-fourth of the optical longitudinal section. There is a small cardia. Intestine, about 8 cells in girth, very obscurely tessellated. The short, blunt, arcuate conoid tail is truncated at the terminus, which has a diameter about one-fourth as great as that of the base. The lateral fields are about one-third as wide as the body, and are composed of 2 rows of cells containing relatively large nuclei.

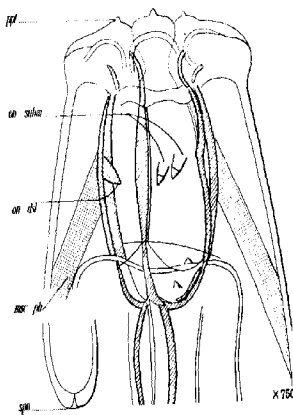
This species rather closely resembles a number of others, and it is by no means certain that it is not identical with some one of them, perhaps constituting a variety. Curiously enough, it was found in Mississippi Bay, Yokohama, Japan. Sublimate to balsam.

43. *M. tridentatus* de Man. At the base of the pharynx are 2 minute denticles. Amphids unknown. Pharynx more or less triquetrous, with three well developed,

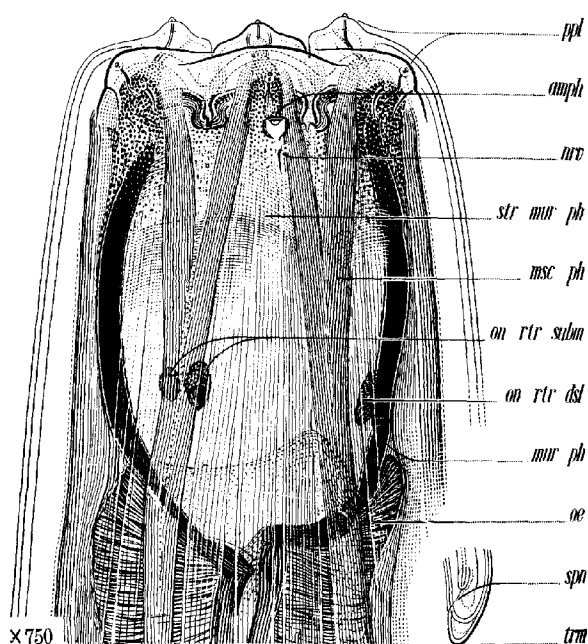
2. 6.5 22. 62.28 89. 3.2 mm  
2.1 2.6 3.1 1.9

2. 6.5 22. 91. 2.7 mm  
2.1 2.6 3.1 2.

double, longitudinal ribs reaching from end to end. (Esophagus at first slightly swollen. Intestine distinctly tessellated. The arcuate tail is conoid to the terminus, which is about one-sixth as wide as the base of the tail. Each of the slender, arcuate spicula is cephalated by contraction and is supplied throughout its length with a median stiffening piece, and is crossed near its distal extremity on the outside by one of the rather broad, two-pointed accessory pieces, which are one-half as long as the spicula. Supplementary organs 15 to 17, apparently conical, 2 to 3 times as far apart anteriorly as posteriorly, where they are nearly contiguous. The posterior member of the series, the whole of which is about one and one-half times as long as the tail, is somewhat smaller than the other members, and is located a short distance in front of the anus. On the tail itself are a number of papillæ, dorsal as well as ventral; 2 pairs on the anterior half, ventral, and 2 pairs on the posterior half, dorsal. It remains uncertain whether there is a spinneret and caudal glands. This striking species seems to be widespread in Europe in moist soil, and is rather common. Fig. 55 (after de Man).



44. *M. gracilicaudatus* n. sp. Intestine about 12 cells in girth. The anterior fifth of the tail is arcuate conoid in such fashion that at the beginning of the second fifth the diameter is about one-third to one-fourth as great as at the anus. Thence on-  
 $\frac{1.4}{1.8} \quad \frac{4.8}{1.6} \quad \frac{21.}{1.8} \quad \frac{-4^{30}}{1.8} \quad \frac{85.}{1.8} \rightarrow 8.1$  mm  
 ward the tail tapers very gradually through the middle third, the posterior portion being cylindroid and somewhat narrower than the spicula. These latter are uniformly arcuate, and about one and one-fourth times as long as the anal body-diameter. At their widest part, toward the proximal end, they are about one-fifth as wide as the corresponding part of the body. They taper gently in each direction, and are not cephalated. The small accessory pieces are of typical form, only about one-fourth as long as the spicula. The series of 19 contiguous supplementary organs is twice as long as the spicula, or equals 3 body diameters. Anteriorly the organs are somewhat larger and also somewhat farther apart. The conical exterior portion of each organ seems to be more or less protrudable. These organs



are similar in form to those of *major*, though they are not echinulate. The anal and post-anal muscles are strongly developed. The anal muscles are found throughout the bulkier portion of the tail. The protruding muscles of the spicula extend backward in the tail to near the point where the tail diminishes rapidly in diameter, and there join the ventral part of the caudal wall. The post-anal papillae are confined largely to the more massive anterior fifth of the tail. On each side there is a ventrally submedian row about as long as the spicula, consisting of 4 to 5 members. Coextensive with them is a ventral row of 3 to 4 papillae. A little distance behind these, where the tail begins to be smaller, there are 2 dorsally submedian

innervated papillæ of smaller size. The supplementary organs are plainly innervated and the nerves can be traced through the cuticle and through the body musculature, and seem to be connected with internal more or less ellipsoidal cells whose nature remains unknown. The spinneret is very inconspicuous. The nature of the caudal glands remains uncertain.

Found in marshy ground, Arlington Farm, Virginia, U. S. A., about the roots of *Impatiens*, in black, clayey soil, with mud. Resembles *M. dolichurus* to a certain extent. It is regrettable that only a few specimens have been available for examination, as it is a species well adapted to throw light on various features of mononch anatomy. Fig. 56 (on the previous page).

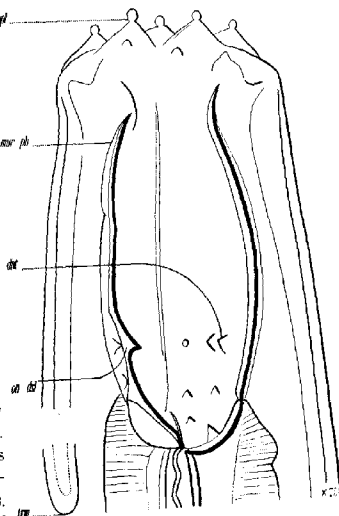
Examination of the pharyngeal muscles of this species leads to a partial understanding of the mechanics of the lips. The muscles which move the lips are long and slender, and pass from the lips backward along the surface of the pharyngeal capsule. They join the body wall some distance behind the pharynx. There are 2 separate groups of muscles, extensors and flexors. Of the 6 extensors 2 are shown in the illustration; these are furcated opposite the middle of the pharynx, one half of each going to the lateral lip; the other half to a submedian lip. The joined fulcræ of the 6 lips form a framework encircling the head. The extensors pass outside this framework. The flexor muscles are less clearly shown, but are manifestly better developed. A group of 3 is shown lying between the 2 extensors. They appear as faint bands outside the pharynx passing forward, and beyond doubt are attached to the lips inside the ring of fulcræ. The musculature of the lips is shown in the illustration and is further explained on page 442 in connection with the general description of the head.

45. *M. dolichurus* Ditlevsen. Neck tapering but little. Pharynx probably prismatic, and in transverse section somewhat triangular. About 7 denticles about the base, or near the base, of the pharynx. The arcuate tail tapers to the terminus, which is about one-eighth as wide as the base. The author mentions

?	?	25.	+80°	78.		4. mm
?	?	?		2.5	1.8	

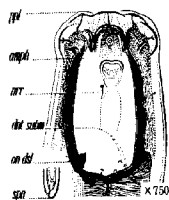
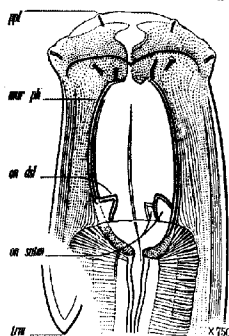
the presence of 3 or 4 inconspicuously developed lobes at the base of the œsophagus, and it would appear from his figures that a spinneret and caudal glands are present, the latter forming a tandem series near the anus. Menzel finds in the pharynx of Swiss specimens of this species 3 teeth of equal size; that is to say, the ventrally submedian teeth are equal in size to the dorsal tooth. His specimens are  $4\frac{1}{2}$  to  $5\frac{1}{2}$  mm. long, and this probably represents the adult size.

Found in moist soil and meadow land, Jutland: Switzerland. Fig. 57 (after Ditlevsen). Menzel shows the papillæ as much less conspicuous, and without the spherical tips. The original material consisted of but a single immature female.



46. *M. digiturus* Cobb. Amphids occur opposite the anterior part of the pharynx. What appears to be a renette pore occurs just behind the nerve-ring. The anal region is somewhat raised. Behind the anus the tail diminishes rapidly in diameter, so that at the end of the anterior fourth it is about three-fifths as wide as at the anus. Thence, for some distance it is cylindrical, but becomes somewhat abruptly convex-conoid in the posterior fifth and ends in a rather narrow, inconspicuous spinneret. The lining of the oesophagus is a conspicuous feature. Intestine not tessellated. The longitudinal ribs of the inner wall of the pharynx are rather conspicuous features, and extend from end to end of the pharynx.

Found about the roots of banana plants, Fiji.  
Fig. 58.

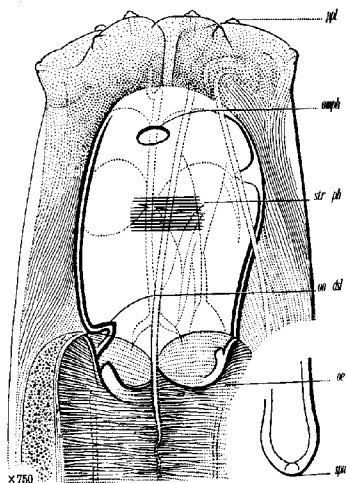


regions teem with nematodes, many of them no doubt, especially adapted to the peculiar conditions found there. The predatory mononchs in such soils will naturally enough have responded in structure not only to the climatic conditions, but also to the form and habits of their quarry. Fig. 59 (just above).

48. *M. gymmolaimus* Cobb. The more or less triquetrous pharynx is strongly three-ribbed. Cardia of such

2.6 6.8 24. 57<sup>15</sup> 86. → 2.9 mm  
2.2 2.3 2.7 2.5 1.8

a nature as to give rise to a double constriction in the cardiac region. Intestine about 12 cells in girth. What appears to be a renette pore occurs immediately behind the nerve-ring. The lateral fields are about one-fifth as wide as the body. The tail tapers regularly to near the terminus; it is, however, cylindroid for a short distance in front of the spinneret. Vulva not prominent. The uterus is as long as the reflexed portion of the ovary, which



47. *M. trichurus*, n. sp. This outstanding form has an oesophagus that is slightly swollen where it receives the pharynx. The lining of the oesophagus is prominent, occupying three-fifths of the optical section. Longitudinal fields one-fourth as wide as the body. Characters well set forth in fig. 14, p. 448.

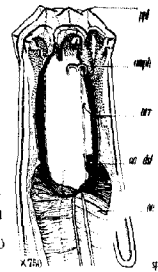
Found about the roots of orange trees, Bahia, Brazil. Bears considerable resemblance to *M. gymmolaimus*. It appears possible from these investigations that the tropical mononchs, when more fully known, will prove especially interesting. Nearly all the more striking species here recorded are from the tropics. The warm soils of the tropical

reaches two-thirds the way back to the vulva. The arranged single file.

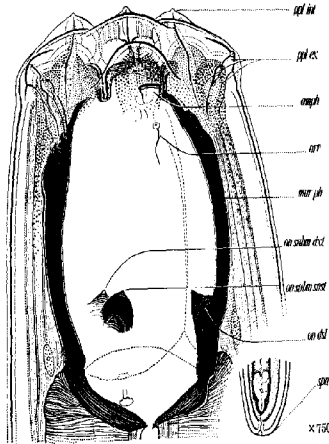
This nemativorous species will probably prove cosmopolitan; of *Platonia insignis*, Rio Janeiro, Brazil; of *Platonia insignis*, Arlington Farm, Virginia, U. S. A. Fig. 60 (on the previous page).

49. *M. consimilis*, n. sp. Amphids, unlike those of *gymnolaimus*, apparently duplex, located a little behind the base of the lips; one-fourth as wide as the corresponding portion of the head. Wall of the pharynx strongly developed.

Rather closely resembles *M. gymnolaimus*, but has the walls of the pharynx much more strongly ceratinized, and is of much smaller size. The pharynx is relatively 50 per cent longer. The spinneret is not swollen as in *gymnolaimus*. Description and figures derived from a single, immature female specimen from about the roots of *Platonia insignis* Mart., Brazil. The figure of *gymnolaimus* shows, on the ventral side, near the front of the pharynx, an inward projection, probably representing the optical section of the junction of elements in the pharyngeal wall. No such appearance was observed in *consimilis*. Fig. 61.



50. *M. rapax*, n. sp. Intestine about 12 to 20 cells in girth, faintly tessellated. The female organs are probably double and symmetrical. The conoid tail tapers somewhat in front of the anus to a plain, symmetrical, unarmed spinneret about one-sixth as wide as its base.



One and one-half tail-lengths in front of the anus there is a constriction in the intestine, which appears to be due to the presence in that region of commissures, as if, possibly, nerves encircled the intestine at that part.

Found about the roots of plants, Arlington Farm, Virginia, U. S. A. Nemativorous. Only young females have been seen. As its name, *rapax*, indicates, this species is a rapacious one, swallowing other nemas whole, even when half as long as itself. Fig. 62.

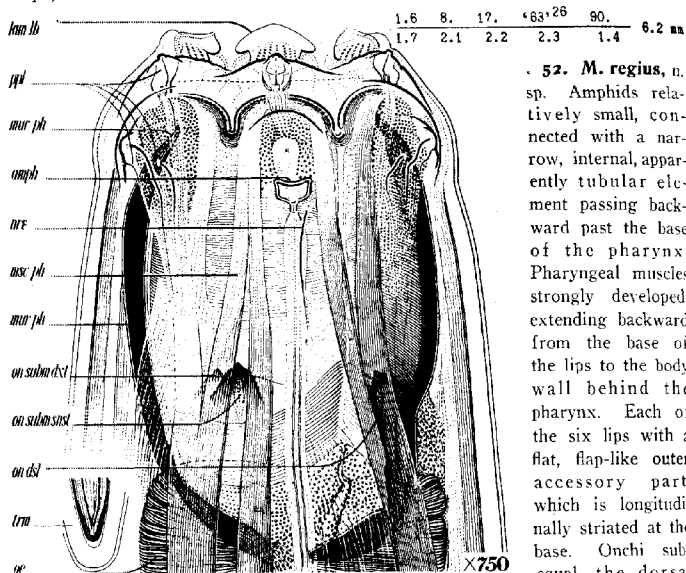
51. *M. rex* Cobb. This "king" of the mononchs has low, broad, inconspicuous labial papillae that do not interfere materially with the rounded contour of the front of the head. The lips are bulky and powerful. No amphids have been seen. The pharynx is armed with very powerful muscles. The intestine is tessellated. The lateral fields are one-fifth as wide as the body. The conoid tail tapers more rapidly at first, being nearly cylindroid in the posterior two-thirds, where it is about one-eighth as wide as at the anus. The spinneret, which is slightly expanded, bears two ventrally submedian papillae, after the manner of *longicaudatus*, but slightly larger

2.	6.	20.	58.37	81.	
1.6	1.7	2.	2.2	1.4	6.5-7. mm
2.	5.5	20.	50	88.	
1.5	1.9	2.1	2.3	1.5	8.5-7. mm



in proportion. Three caudal glands are present. Each uterus is capable of carrying one and possibly two eggs at a time. These are about one and one-fourth times as long as the body is wide, and half as wide as long. The tail of the male tapers more rapidly at first than that of his mate. Supplementary organs 17, prominent, closely approximated, equidistant, occupying a space equal to one and one-half times the length of the tail. The spicula are about twice as long as the anal body-diameter.

Found at depths of from about 200 to 1200 feet in Lakes Manapouri and Wakatipu, New Zealand.



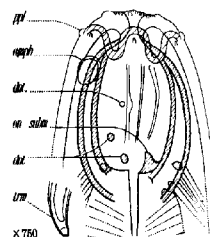
52. *M. regius*, n. sp. Amphids relatively small, connected with a narrow, internal, apparently tubular element passing backward past the base of the pharynx. Pharyngeal muscles strongly developed, extending backward from the base of the lips to the body wall behind the pharynx. Each of the six lips with a flat, flap-like outer accessory part, which is longitudinally striated at the base. Onchi subequal, the dorsal

slightly the stronger. Found about the roots of plants, Arlington Farm, Virginia, U. S. A. Fig. 63.

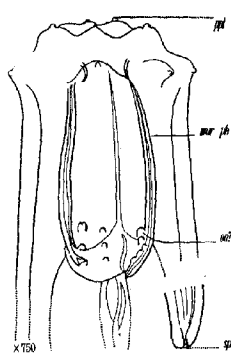
53. *M. bathybius* Micoletzky. In the figure the onchus labeled "submedian" is really a subdorsal onchus. In addition to this subdorsal onchus there are still others, probably 4.9 10. 30. 63<sup>7</sup> 87. .8 mm  
2 to 3 pairs, which 3.3 3.8 3.9 3.4 2.5  
in profile view have a double contour. It remains uncertain whether the other markings seen on the wall of the pharynx are projections or pores.

The author considers this species to be related to *M. gerlachei* de Man, the lip region and vestibule of the two species being similar. However, the armature of the pharynx in the two species is quite different.

Found in mud at a depth of about 300 feet in the Atter Lake, Austria. The description and figures rest upon the examination of a single immature specimen, and it is probable that the examination of further specimens will improve our knowledge of this interesting form. Fig. 64 (after Micoletzky).



54. *M. studeri* Steiner. Wall of the pharynx presenting 5 longitudinal ribs, four of them in 2 pairs, the fifth single. At the base of the pharynx numerous small denticles, arranged in rows of from three to four. (Esophagus powerful.



2.8? ? 26. 67. 94. 2. mm A little in front of the posterior end of the esophagus there are 3 powerful teeth which, according to Steiner, "are similar to those seen in *Mononchus dolichurus*."

Tail of the male arcuate, conoid to the spinneret, which is about one-fourth as wide as the base. The three caudal glands form a tandem series in the anterior half of the tail. The slightly arcuate spicula in their widest part are about one-sixth as wide as the corresponding portion of the body. They taper slightly at either end, and are about one and one-third times as long as the anal body-diameter. They are not cephalated. The accessory pieces appear to be of the usual character. The twelve short, tubular, equidistant supplementary organs, occupying a space equal to twice the length of the tail, do not interfere materially with the ventral contour. The internal tubular parts are about as long as the spicula are wide. Distance from the anus to the posterior supplementary organ is nearly twice as great as the distance between the adjacent organs. Two pairs of post-anal papillae were noted.

Found on the island of Ufenau in the Zürich Lake, under moss. Fig. 65 (after Steiner).

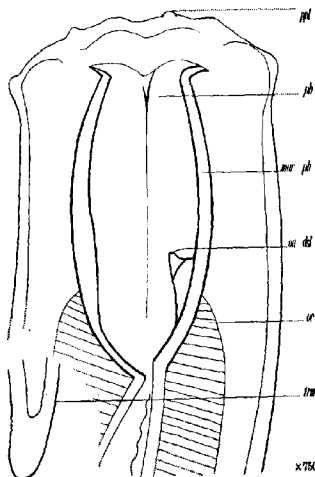
55. *M. zschokkei* Menzel. This species, one male to each three to four females, is found in various parts of the Austrian and Swiss Alps. Neck and esophagus

3.2? ? 25. 86. 95. 2.2-3.2 mm

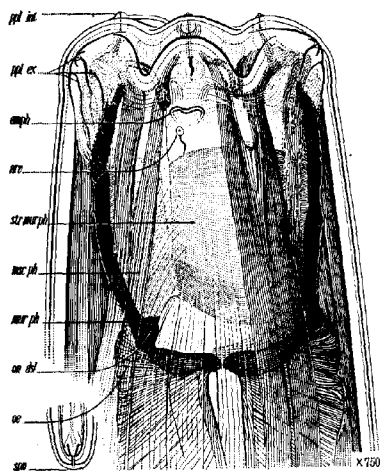
? ? ? 3.4 2.1 ? ? ? 25. M 96. 2.4-3.5 mm

tapering but little. Small denticles often occur at the base of the pharyngeal cavity. Uterus capable of containing one or two eggs. The blunted terminus of the conoid arcuate tail is about one-eighth as wide as the base. The slightly arcuate spicula are rather slender, each, however, having a stiffening piece in its distal half. Accessory pieces as figured by de Man for his *M. brachyuris* Bütschli. Beginning near the anus the 21 projecting, obliquely conical, equidistant, contiguous supplementary organs, each as high as wide, occupy a space 3 times as long as the tail.

Found in the high Swiss Alps. Fig. 67, after Menzel, who considers that of all the European mononchs at present known, *zschokei* has close affinity only with *M. parvus* de Man, from which it differs in the position of the onchus and the relative abundance of males.



56. *M. brachylaimus*, n. sp. There are two exceedingly minute, almost invisible, apparently rudimentary, ventrally submedian, conical, forward-pointing toothlets at the base of the pharynx. These are not shown in the illustration. Three slightly



2.4	7.	21.	65 <sup>14</sup>	94.	
2.4	2.4	2.8	3.	1.9	3.2
2.3	7.4	19.	42	94.	
2.2	2.3	2.5	2.5	2.	3.5

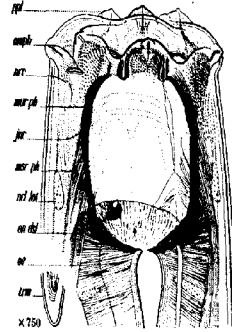
arcuate, duplex, longitudinal ribs strengthen the walls of the pharynx and reach from end to end, one being dorsal, the other two ventrally submedian. Amphids difficult to see. Oesophagus at first slightly expanded. The oesophageal lining is not so prominent as in many other species; its optical section finds expression in 3 or 4 parallel lines, occupying about one-fourth of the longitudinal optical section. There is an inconspicuous, flattish cardia. Intestine about 8 to 12 cells in girth, faintly tessellated. The tail is conoid to the plain, unarmed conoid terminus.

The base of the spinneret is about one-fifth as wide as the base of the tail. The clavate caudal glands form a close tandem in the anterior third of the tail. The anus has rather conspicuous, with well developed, though not protruding lips. There is a pair of innervated lateral papillae near the middle of the tail of the female. Both in front of and behind the vulva, especially behind, there are inconspicuous papillae, occupying a distance equal to twice to thrice the length of the body-diameter. The two equal, arcuate, rather slender spicula are one and one-half times as long as the anal body-diameter, and are of nearly uniform size throughout the greater part of their length. However, beginning near the slightly truncated tips they taper slightly in the distal sixth. The proximal ends are also narrowed slightly and lie well toward the dorsal side of the body, at any rate when the body is incurved. The two accessory pieces, each about two-thirds as wide as the spicula, are located opposite the distal portions of these latter. When seen in profile they appear to lie nearly at right angles to the body axis, and seem to cross the distal parts of the spicula. They are about two to three times as long as wide, and their distal extremities are diminished and bifurcated, the two prongs of the fork forming a U-shaped figure. When at rest these accessory pieces, as usual, are well inside the anus, in fact appear as if lying immediately under the lateral fields. In front of the anus there is a uniform series of about 16 equidistant, closely approximated, innervated supplementary organs, occupying a distance about equal to the length of the tail. When the tail end of the body is incurved, each organ appears on the ventral contour as a flattish cone, at the apex of which is a nerve ending, which from this point extends inward and forward.

Brown, sandy soil, Arlington Farm, Virginia, U. S. A. This nematode is distinguished from all others by the relative broadness of the pharynx, and by the position and size of the basal onchi. Especially well adapted to show the structure of the lip muscles and other organs of the head. Fig. 67.

57. *M. acutus*, n. sp. Oesophagus bulbous at first, the swelling being prolate. Intestine about 10 cells in girth. The arcuate conoid tail is practically acute. There is a pair of 2.6 7.5 22. 45<sup>1</sup> 94. sublateral, 2.7 3.2 3.3 3.4 12.6 2.1 an innervated papillæ near the beginning of the posterior third of the tail. Anus not raised. Fig. 68.

Found about the roots of rhubarb in loose, brown, sandy soil, Arlington Farm, Virginia, U. S. A. Nemativorous. One specimen was observed which had swallowed another mononch. This is one of the most instructive forms. It is desirable that the more minute structural details of nemas be very carefully investigated with a view to increasing our knowledge of their comparative anatomy. The different parts of the digestive organs of nemas, small as they are, are as profoundly modified in harmony with the nature of the food as those of higher animals. The digestion of starch requires a different organic mechanism from that for digesting meat. The nemas have specialized to a high degree in the matter of food, and their digestive organs are correspondingly diversified.



#### MONONCHS AND SOIL FERTILITY

No one with a grain of imagination can engage in such studies as the foregoing without sooner or later asking himself questions of a general nature concerning the biology of the soil; for he gradually comes to see how almost infinitely numerous and varied are the organisms inhabiting the soil; a population of which the nemas are only one example. The answers to these questions will lead to a new view of soil fertility.

The revolution wrought by Liebig's ideas concerning the chemistry of the soil spent itself only to show us that, grand as it was, it was little more than an overture. Subtler forces and more intricate relationships than any indicated in these earlier conceptions must be considered. We now see, or are beginning to see, that the value of manure and of the rotation of crops is to be explained not simply on the basis of the exhaustion of certain elements in the soil, but also, and probably in some instances mainly, on the basis of an opposite process, an accumulation of certain organisms and substances in the soil. Who knows but that the existence of annuals may be due in some measure to this latter fact? May not these elaborate provisions for the distribution of the seeds of annuals be in some measure a means of escaping these accumulated hostile forces in the soil?

After all the word Agriculture is more or less of a misnomer. We cultivate, not so much the field, as plants. What we are really after is sunshine, for we are lost unless we can convert our infinitesimal part of the energy of this nearest star into food, clothing and shelter. This we do by utilizing the life forces of certain plants and animals, and these are not so few as we dreamed in our older philosophy, for none of our "domesticated organisms" can any longer be considered by itself. Every

such organism is reared in the midst of a host of other organisms, visible and invisible, and often it is these others that determine agricultural success or failure.

The soil is the habitation of a vast community of beings with all the attributes of other huge agglomerations of living things having varying needs, instincts and aspirations; and it is just as inappropriate to look upon it as inorganic as it would be to look upon a great city as merely an agglomeration of hills, streets and houses. Here in the soil are beings in enormous variety; multiplying, growing, dying; competing, fighting, co-operating one with another, with an activity almost if not quite defying the imagination, and we need what may be called soil biologists or geobiologists, who shall understand, as far as possible, this interplay of life forces that gives us food, fiber and fuel. To a considerable degree our progress in agricultural knowledge in the not distant future will be in proportion to the firmness with which we lay hold of and act on this idea.

#### SUMMARY

1. The genus *Mononchus* is composed of scores, possibly hundreds, of species, divisible into distinct subgenera. The number of known species is hereby more than doubled.

2. The genus is of world-wide distribution, and many of the species are cosmopolitan. Mononchs occur in all kinds of arable soil, sometimes in hundreds of millions per acre.

3. Most mononchs, probably all, are strictly carnivorous. They feed on a variety of living microzoa, prominent among which are other nemas.

4. Injurious nemas are devoured by mononchs, and it is desirable that this trait of mononchs be carefully investigated with a view to utilizing it, if possible, in diminishing the enormous crop losses due to plant infesting nemas—losses amounting to many millions of dollars annually.

5. The lips are moved by long muscles, connecting proximally with the body wall behind the pharynx. These muscles lie along the outer surface of the pharyngeal capsule and act in such a way as to pull the lips inward and outward radially about a series of fulcra existing in a framework encircling the head along the margin of the pharynx. The lips are the mechanical complements of the dorsal tooth and denticles. While most mononchs bolt their food, some give it a certain degree of mastication. The appetite is sometimes voracious.

6. Many mononchs, probably most, are hermaphroditic, even to the degree of syngonism. In the typical case investigated the minute sperm cells of female origin are functional.

7. Well developed glands, salivary in character, occur in the mononch oesophagus, and empty directly into its lumen, and both indirectly and directly into the mouth cavity.

8. What appears to be an excretory pore of the usual type seems universal near the nerve ring.
9. The outer labial papillæ are the homologues of the ordinary cephalic setæ of other nemas, and are therefore most probably tactile in function. This leaves it probable that the inner papillæ are devoted to the senses of taste and smell.
10. Amphids are always present in the form of small lateral more or less elliptical structures near the lips, and are connected with internal elements extending inward and backward.
11. A functional spinneret is present in a majority of the species.
12. The cuticle is always finely transversely striated.
13. Mononchs probably moult four times.

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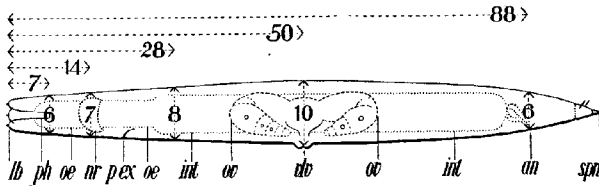
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## APPENDIX



The above diagram illustrates the decimal formula used herein. 6, 7, 8, 10, 6 are the transverse measurements, while 7, 14, 28, 50, 88 are the corresponding longitudinal measurements. The formula in this case is:

$$\frac{6}{7} \cdot \frac{7}{14} \cdot \frac{8}{28} \cdot \frac{10}{50} \cdot \frac{6}{88}$$

The unit of measurement is the hundredth part of the length of the body, whatever that may be. The measurements become, therefore, percentages of the length. The absolute length is given in millimeters as a final non-paired term.

The measurements are taken with the animal viewed in profile; the first are taken at the base of the pharynx, the second at the nerve-ring, the third at the cardiac constriction or end of the neck, the fourth at the vulva in females and at the middle (M) in males, the fifth at the anus.

Since the measurements vary somewhat with varying technique, brief notes as to the method of fixation and preservation are inserted. Usually the formulae represent an average of several adult individuals.

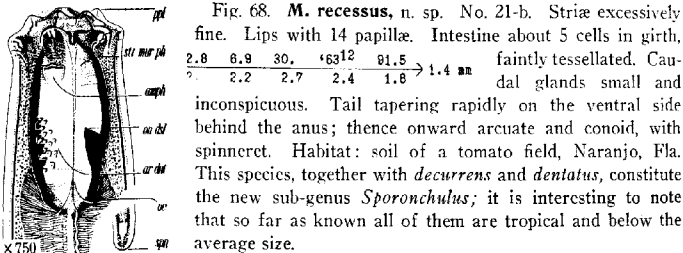


Fig. 68. *M. recessus*, n. sp. No. 21-b. Striae excessively fine. Lips with 14 papillae. Intestine about 5 cells in girth, faintly tessellated. Caudal glands small and inconspicuous. Tail tapering rapidly on the ventral side behind the anus; thence onward arcuate and conoid, with spinneret. Habitat: soil of a tomato field, Naranja, Fla. This species, together with *decurrens* and *dentatus*, constitute the new sub-genus *Sporonchulus*; it is interesting to note that so far as known all of them are tropical and below the average size.

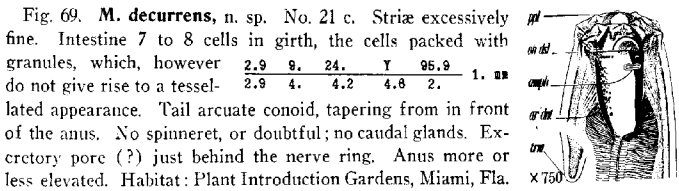


Fig. 69. *M. decurrens*, n. sp. No. 21 c. Striae excessively fine. Intestine 7 to 8 cells in girth, the cells packed with granules, which, however, do not give rise to a tessellated appearance. Tail arcuate conoid, tapering from in front of the anus. No spinneret, or doubtful; no caudal glands. Excretory pore (?) just behind the nerve ring. Anus more or less elevated. Habitat: Plant Introduction Gardens, Miami, Fla.

53-b. *M. fasciatus*, n. sp. Like *M. bathybius*, No. 53. Characterized by large, powerful lips, set off by a deep constriction, in 2.4 5.6 16. '64' 90. the depths of which is a double refractive line. 2.3 2.3 2.4 2.4 1.8 2.2 mm. Teeth 3, small, equal, sub-basal; tail conoid, no spinneret. Papillae 14. Habitat: About roots of camphor, Florida. Nemativorous.

# THE EFFECT OF SOIL REACTION ON THE AVAILABILITY OF AMMONIUM SULFATE<sup>1</sup>

By

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## INTRODUCTION

In applying any fertilizer to a soil it is essential to know the factors which influence its availability. Under favorable conditions nitrogenous fertilizers which are not already in the nitrate form are rapidly nitrified and the nitrate produced assimilated by plants. In acid soils it has been shown repeatedly that nitrification proceeds very slowly, but few cases have been reported where the soil produced no nitrates at all. If, then, there is always some nitrification in acid soils, is lime absolutely essential for a sufficient quantity of nitrates to be produced to satisfy the demands of a crop, provided there is a liberal application of ammonium salts or organic fertilizers? To attempt at least partially to answer this question from the standpoint of ammonium sulfate, the following experiment was carried out.

Three soils were chosen, a sand with a lime-requirement of 3,000 pounds of calcium oxide per acre, a sandy loam with a similar lime requirement, and a silt loam with a lime-requirement of 4,000 pounds of calcium oxide. The soils were dried, sieved, thoroughly mixed, and weighed out into small pots at the rate of 5 pounds of sand, 10 pounds of sandy loam, and 6.5 pounds for the silt loam per pot. Calculations were based on the assumption that an acre-foot of sand weighs 4,000,000 pounds, sandy loam 3,200,000, and silt loam 2,800,000 pounds. All of the pots received an excess of potassium and phosphorous. The amounts of calcium oxide and ammonium sulfate varied and are indicated in each table separately. The fertilizers were mixed with the entire amount of soil in the pots, buckwheat planted and the soil made up to optimum moisture content. Two crops of buckwheat were grown on the same soils in the greenhouse. The first of these is reported in Tables I, II and III.

## FIRST CROP

The crop yields and the per cent of nitrogen in buckwheat from the sand are given in Table I. It will be noticed that as the amount of lime increased, the crop yields also increased for the smaller applications of CaO, where no ammonium sulfate was applied the maximum crop produced was at 2,000 pounds alkalinity, larger amounts of calcium oxide producing a slight decrease. In the presence of ammonium sulfate the

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largest yield was obtained with the soil still 1000 pounds acid, large amounts being harmful or at least less efficient than the smaller applications. The per cent of nitrogen in the crop from the pots receiving no nitrogen increased with small applications of calcium oxide, but decreased when the soil was made neutral or alkaline. In the case of the pots receiving ammonium sulfate, the per cent of nitrogen shows a

TABLE I  
THE EFFECT OF SOIL REACTION ON THE AVAILABILITY OF AMMONIUM SULFATE  
IN SAND

Pot No.	Reaction of Soil as Pounds CaO	Mg. N Added	Yield, gm.	Av. gm.	Increase over Check	Per cent Increase	Per cent N	Total Mg. N	Av. Mg. N	Per cent Increase over Check	Per cent Increase	Per cent N Recovered
1	3000 lbs. acid....	0	3.0	.....	.....	.....	1.22	36.6	.....	.....	.....	.....
2	3000 lbs. acid....	0	3.7	3.35	.....	.....	1.03	38.1	37.4	.....	.....	.....
3	3000 lbs. acid....	155	4.9	.....	.....	.....	1.98	97.0	.....	.....	.....	.....
4	3000 lbs. acid....	155	4.2	4.55	1.20	35.8	2.15	86.4	91.7	54.3	145.2	35.0
5	2000 lbs. acid....	0	3.7	.....	.....	.....	1.33	49.2	.....	.....	.....	.....
6	2000 lbs. acid....	0	3.9	3.80	.....	.....	1.33	51.9	50.6	.....	.....	.....
7	2000 lbs. acid....	155	9.2	.....	.....	.....	1.34	123.3	.....	.....	.....	.....
8	2000 lbs. acid....	155	7.1	8.15	4.35	114.5	1.45	103.0	113.2	62.6	123.7	40.4
9	1000 lbs. acid....	0	3.2	.....	.....	.....	1.37	43.8	.....	.....	.....	.....
10	1000 lbs. acid....	0	4.0	3.60	.....	.....	1.53	61.2	52.5	.....	.....	.....
11	1000 lbs. acid....	155	8.8	.....	.....	.....	1.39	122.3	.....	.....	.....	.....
12	1000 lbs. acid....	155	10.0	9.40	5.80	161.1	1.24	124.0	123.2	70.7	134.7	45.6
13	Neutral .....	0	4.4	.....	.....	.....	1.05	46.2	.....	.....	.....	.....
14	Neutral .....	0	4.5	4.45	.....	.....	1.16	52.2	49.2	.....	.....	.....
15	Neutral .....	155	10.6	.....	.....	.....	1.19	126.1	.....	.....	.....	.....
16	Neutral .....	155	6.1	8.35	3.90	87.6	1.50	91.5	108.8	59.6	121.1	49.6
17	1000 lbs. alkaline	0	4.6	.....	.....	.....	1.03	47.4	.....	.....	.....	.....
18	1000 lbs. alkaline	0	4.9	4.75	.....	.....	1.02	50.0	48.7	.....	.....	.....
19	1000 lbs. alkaline	155	9.0	.....	.....	.....	1.06	95.4	.....	.....	.....	.....
20	1000 lbs. alkaline	155	7.0	8.00	3.25	68.5	1.14	79.8	87.6	38.9	79.9	25.1
21	2000 lbs. alkaline	0	5.6	.....	.....	.....	1.03	57.7	.....	.....	.....	.....
22	2000 lbs. alkaline	0	5.7	5.65	.....	.....	0.96	54.7	56.2	.....	.....	.....
23	2000 lbs. alkaline	155	7.0	.....	.....	.....	1.37	95.9	.....	.....	.....	.....
24	2000 lbs. alkaline	155	7.8	7.40	1.75	30.9	1.11	86.6	91.3	35.1	62.5	22.6
25	3000 lbs. alkaline	0	3.1	.....	.....	.....	1.17	36.3	.....	.....	.....	.....
26	3000 lbs. alkaline	0	5.7	4.40	.....	.....	1.19	67.8	52.1	.....	.....	.....
27	3000 lbs. alkaline	155	7.2	.....	.....	.....	0.99	71.3	.....	.....	.....	.....
28	3000 lbs. alkaline	155	7.5	7.35	2.95	67.0	1.10	82.5	76.9	24.8	47.6	16.0

rather uniform and marked decrease as the amount of lime added increases. The percentage recovery of the nitrogen applied increases uniformly from 35 per cent at the highest acidity to 49.6 per cent at the neutral point and then again decreases very markedly to 16 per cent at the highest alkalinity.

The results obtained with the sandy loam are given in Table II. In the pots receiving no ammonium sulfate it will be noticed that there is a marked increase in crop yields as the amount of lime applied increases, except at the highest rate of application where an appreciable

decrease is noticed. The yields where ammonium sulfate was used increased with small applications of calcium oxide, as was true with the sandy soil, previously discussed, but show a decrease with the larger rates of application. The per cent of nitrogen in the crop from the pots receiving no nitrogen shows a steady increase as the amount of lime present increases. In the crop from the ammonium sulfate pots the differences are very slight except in the very alkaline soils which show some increases in the per cent of nitrogen. The percentage recovery of the nitrogen applied was highest at an acidity of 2000 pounds and decreased as the soil was made more alkaline.

TABLE II  
THE EFFECT OF SOIL REACTION ON THE AVAILABILITY OF AMMONIUM SULFATE  
IN SANDY LOAM

Pot No.	Reaction of Soil as Pounds CaO	Mg. N Added	Yield, gm.	Av. gm.	Increase over Check	Per cent Increase	Per cent N	Total Mg. N	Av. Mg. N	Increase over Check	Per cent Increase	Per cent N recovered
29	3000 lbs. acid....	0	8.2	.....	.....	.....	0.74	60.7	.....	.....	.....	.....
30	3000 lbs. acid....	0	8.9	8.55	.....	.....	0.79	70.3	65.5	.....	.....	.....
31	3000 lbs. acid....	310	19.6	.....	.....	.....	1.35	264.6	.....	.....	.....	.....
32	3000 lbs. acid....	310	16.5	18.05	9.50	111.1	1.39	229.4	247.0	181.5	277.1	58.6
33	2000 lbs. acid....	0	10.4	.....	.....	.....	0.71	73.8	.....	.....	.....	.....
34	2000 lbs. acid....	0	8.0	9.20	.....	.....	0.87	69.6	71.7	.....	.....	.....
35	2000 lbs. acid....	310	19.4	.....	.....	.....	1.25	242.5	.....	.....	.....	.....
36	2000 lbs. acid....	310	21.5	20.45	11.25	122.3	1.31	281.7	262.1	190.4	265.5	61.4
37	1000 lbs. acid....	0	11.7	.....	.....	.....	0.95	111.2	.....	.....	.....	.....
38	1000 lbs. acid....	0	11.0	11.35	.....	.....	0.80	88.0	99.6	.....	.....	.....
39	1000 lbs. acid....	310	25.0	.....	.....	.....	1.19	297.5	.....	.....	.....	.....
40	1000 lbs. acid....	310	22.0	23.50	12.15	106.8	1.22	268.4	283.0	183.4	184.1	59.1
41	Neutral .....	0	16.5	.....	.....	.....	0.76	125.4	.....	.....	.....	.....
42	Neutral .....	0	14.3	15.40	.....	.....	0.79	113.0	119.2	.....	.....	.....
43	Neutral .....	310	21.2	.....	.....	.....	1.33	282.0	.....	.....	.....	.....
44	Neutral .....	310	21.2	21.20	5.80	37.7	1.31	277.7	279.9	160.7	134.8	51.8
45	1000 lbs. alkaline	0	15.8	.....	.....	.....	0.93	146.9	.....	.....	.....	.....
46	1000 lbs. alkaline	0	15.2	15.50	.....	.....	0.93	141.4	144.2	.....	.....	.....
47	1000 lbs. alkaline	310	23.1	.....	.....	.....	1.17	270.3	.....	.....	.....	.....
48	1000 lbs. alkaline	310	21.5	22.30	6.80	43.9	1.41	303.2	286.8	142.6	98.9	46.0
49	2000 lbs. alkaline	0	16.5	.....	.....	.....	1.06	174.9	.....	.....	.....	.....
50	2000 lbs. alkaline	0	17.8	17.15	.....	.....	0.93	165.5	170.2	.....	.....	.....
51	2000 lbs. alkaline	310	20.3	.....	.....	.....	1.33	270.0	.....	.....	.....	.....
52	2000 lbs. alkaline	310	16.5	18.40	1.35	7.9	1.71	282.2	276.1	105.9	62.2	34.1
53	3000 lbs. alkaline	0	14.4	.....	.....	.....	1.25	180.0	.....	.....	.....	.....
54	3000 lbs. alkaline	0	14.9	14.65	.....	.....	1.24	184.8	182.4	.....	.....	.....
55	3000 lbs. alkaline	310	19.4	.....	.....	.....	1.66	322.0	.....	.....	.....	.....
56	3000 lbs. alkaline	310	21.3	20.35	5.70	38.9	1.53	325.9	324.0	141.6	77.6	45.7

In Table III the data obtained for the silt loam are tabulated. The figures show an increase in crop yield of from 14.15 gm. at an acidity of 4000 pounds to 23 gm. at 3000 pounds alkalinity in the absence of other than soil nitrogen. With ammonium sulfate present, liming had little effect on the crop yields. In the per cent of nitrogen there is little difference due to liming.

## SECOND CROP

After harvesting the buckwheat from the above pots the upper two inches of soil in each pot were cultivated, buckwheat again planted and the same amount of ammonium sulfate added to the pots as was originally used. The ammonium sulfate was added in solution to the surface of the soil. No additional potash or phosphorous was applied.

TABLE III  
THE EFFECT OF SOIL REACTION ON THE AVAILABILITY OF AMMONIUM SULFATE  
IN SILT LOAM

Pot No.	Reaction of Soil as Pounds CaO	Mg. N Added	Yield, gm.	Av. gm.	Increase over Check	Per cent Increase	Per cent N	Total Mg. N	Av. Mg. N	Increase over Check	Per cent Increase	Per cent N Recovered
57	4000 lbs. acid....	0	14.4	.....	.....	.....	0.86	123.8	.....	.....	.....	.....
58	4000 lbs. acid....	0	13.9	14.15	.....	.....	0.87	120.9	122.4	.....	.....	.....
59	4000 lbs. acid....	207	21.9	.....	.....	.....	1.14	249.7	.....	.....	.....	.....
60	4000 lbs. acid....	207	21.4	21.65	7.50	53.0	1.19	254.7	252.2	129.8	106.0	62.7
61	3000 lbs. acid....	0	14.6	.....	.....	.....	0.87	127.0	.....	.....	.....	.....
62	3000 lbs. acid....	0	14.0	14.30	.....	.....	1.13	158.2	142.6	.....	.....	.....
63	3000 lbs. acid....	207	22.7	.....	.....	.....	1.11	252.0	.....	.....	.....	.....
64	3000 lbs. acid....	207	21.6	22.15	7.85	54.9	1.27	274.3	263.2	120.6	84.6	58.2
65	2000 lbs. acid....	0	16.5	.....	.....	.....	0.83	137.0	.....	.....	.....	.....
66	2000 lbs. acid....	0	14.5	15.50	.....	.....	0.99	143.6	140.3	.....	.....	.....
67	2000 lbs. acid....	207	24.1	.....	.....	.....	1.16	279.6	.....	.....	.....	.....
68	2000 lbs. acid....	207	23.2	23.65	8.15	52.6	1.19	276.1	277.9	137.6	98.1	66.5
69	1000 lbs. acid....	0	17.0	.....	.....	.....	0.73	124.1	.....	.....	.....	.....
70	1000 lbs. acid....	0	16.0	16.50	.....	.....	0.98	156.8	140.5	.....	.....	.....
71	1000 lbs. acid....	207	24.0	.....	.....	.....	1.21	290.4	.....	.....	.....	.....
72	1000 lbs. acid....	207	20.7	22.35	5.85	35.5	1.35	279.5	285.0	144.5	102.8	69.8
73	Neutral .....	0	17.1	.....	.....	.....	0.98	167.6	.....	.....	.....	.....
74	Neutral .....	0	13.9	15.50	.....	.....	1.08	148.1	157.9	.....	.....	.....
75	Neutral .....	207	24.1	.....	.....	.....	1.13	272.3	.....	.....	.....	.....
76	Neutral .....	207	20.6	22.35	6.85	44.2	1.45	298.7	285.5	127.6	80.8	61.6
77	1000 lbs. alkaline	0	18.2	.....	.....	.....	0.90	163.8	.....	.....	.....	.....
78	1000 lbs. alkaline	0	18.0	18.10	.....	.....	1.03	185.4	174.6	.....	.....	.....
79	1000 lbs. alkaline	207	18.0	.....	.....	.....	1.45	261.0	.....	.....	.....	.....
80	1000 lbs. alkaline	207	23.0	20.50	2.40	13.3	1.25	287.5	274.3	99.7	57.1	48.1
81	2000 lbs. alkaline	0	16.8	.....	.....	.....	0.87	146.2	.....	.....	.....	.....
82	2000 lbs. alkaline	0	19.0	17.90	.....	.....	0.92	174.8	160.5	.....	.....	.....
83	2000 lbs. alkaline	207	23.6	.....	.....	.....	1.21	285.6	.....	.....	.....	.....
84	2000 lbs. alkaline	207	24.6	24.10	6.20	34.6	1.16	279.4	282.5	122.0	76.0	58.9
85	3000 lbs. alkaline	0	23.0	.....	.....	.....	1.07	246.1	.....	.....	.....	.....
86	3000 lbs. alkaline	0	.....	23.00	.....	.....	.....	.....	246.1	.....	.....	.....
87	3000 lbs. alkaline	207	22.4	.....	.....	.....	1.39	311.4	.....	.....	.....	.....
88	3000 lbs. alkaline	207	24.7	23.55	0.55	2.4	1.25	308.8	310.1	64.0	26.4	30.9

The results obtained with the sand are given in Table IV. The yields in the sand are largest near the neutral point where no nitrogen was applied and decrease somewhat as more lime is added, but the decrease is probably due to the smaller amounts of nitrogen in these soils because the previous crop had been larger. With ammonium sulfate the best results are obtained near the neutral point. At the highest acidity it will be noticed that no crop could be grown in the presence of the rela-

tively large amount of ammonium sulfate. The per cent of nitrogen in the crop varied only slightly in the check pots, but in the nitrogen pots there is always a marked decrease as the crop yield increases. The more acid soils, therefore, show the higher per cent of nitrogen. The recovery of nitrogen is small because of the large amount applied and the limited quantity of soil used. There is a fairly uniform decrease as the application of lime increases.

TABLE IV  
THE EFFECT OF SOIL REACTION ON THE AVAILABILITY OF AMMONIUM SULFATE IN SAND

Pot No.	Reaction of Soil as Pounds CaO	Mg. N Added	Yield, gm.	Average gm.	Increase over Check	Per cent Increase	Per cent N	Total Mg. N	Average Mg. N	Increase over Check	Per cent Increase	Per cent N Recovered
1	3000 lbs. acid....	0	1.2	.....	.....	.....	1.11	13.3	.....	.....	.....	.....
2	3000 lbs. acid....	0	1.1	1.15	.....	.....	1.11	12.2	12.8	.....	.....	.....
3	3000 lbs. acid....	155	0.0	.....	.....	.....	0.00	0.0	.....	.....	.....	.....
4	3000 lbs. acid....	155	0.0	0.00	-1.15	0.0	0.00	0.0	0.0	12.8	0.0	0.0
5	2000 lbs. acid....	0	1.1	.....	.....	.....	1.35	14.9	.....	.....	.....	.....
6	2000 lbs. acid....	0	1.2	1.15	.....	.....	1.04	12.5	13.7	.....	.....	.....
7	2000 lbs. acid....	155	3.3	.....	.....	.....	2.19	71.3	.....	.....	.....	.....
8	2000 lbs. acid....	155	2.9	3.10	1.95	170.0	2.41	69.9	71.1	57.4	419.0	37.0
9	1000 lbs. acid....	0	2.0	.....	.....	.....	1.03	20.3	.....	.....	.....	.....
10	1000 lbs. acid....	0	1.0	1.50	.....	.....	0.93	9.3	14.8	.....	.....	.....
11	1000 lbs. acid....	155	3.8	.....	.....	.....	1.57	59.7	.....	.....	.....	.....
12	1000 lbs. acid....	155	3.6	3.70	2.20	146.7	1.77	63.7	61.7	46.9	316.9	30.2
13	Neutral .....	0	2.0	.....	.....	.....	0.87	17.4	.....	.....	.....	.....
14	Neutral .....	0	1.0	1.50	.....	.....	0.77	7.7	12.6	.....	.....	.....
15	Neutral .....	155	3.4	.....	.....	.....	1.55	52.7	.....	.....	.....	.....
16	Neutral .....	155	4.8	4.10	2.60	173.3	1.35	64.8	58.8	46.2	366.7	29.8
17	1000 lbs. alkaline	0	1.0	.....	.....	.....	0.95	9.5	.....	.....	.....	.....
18	1000 lbs. alkaline	0	1.0	1.00	.....	.....	1.01	10.1	9.8	.....	.....	.....
19	1000 lbs. alkaline	155	2.7	.....	.....	.....	1.39	37.5	.....	.....	.....	.....
20	1000 lbs. alkaline	155	3.5	3.10	2.10	210.0	1.66	58.1	47.8	38.0	387.8	24.5
21	2000 lbs. alkaline	0	0.8	.....	.....	.....	1.05	8.4	.....	.....	.....	.....
22	2000 lbs. alkaline	0	0.8	0.80	.....	.....	0.98	7.8	8.1	.....	.....	.....
23	2000 lbs. alkaline	155	2.0	.....	.....	.....	1.50	45.0	.....	.....	.....	.....
24	2000 lbs. alkaline	155	3.1	3.05	2.15	256.2	1.72	53.3	49.1	41.0	506.2	26.4
25	3000 lbs. alkaline	0	1.0	.....	.....	.....	1.38	13.8	.....	.....	.....	.....
26	3000 lbs. alkaline	0	1.8	1.40	.....	.....	1.01	18.2	16.0	.....	.....	.....
27	3000 lbs. alkaline	155	3.7	.....	.....	.....	1.48	54.8	.....	.....	.....	.....
28	3000 lbs. alkaline	155	4.0	3.85	2.45	175.0	1.49	59.6	57.2	41.2	257.5	26.5

The yields for the sandy loam are given in Table V. In the sandy loam there is a gradual increase with variations in the amount of crop produced with the increasing applications of calcium oxide. As will be remembered, the first crop from these pots had shown decreases at the higher rates of application. The per cent of nitrogen in the crop agrees well with the results obtained in the sand, the differences in the checks due to liming being very small, but in the presence of ammonium sulfate there is a decrease with the increase in the amount of calcium oxide, or, in other words, with the increase in crop yields. Small amounts of

lime increased the recovery of nitrogen and were just as efficient from this standpoint as the larger applications.

The second crop of buckwheat from the silt loam soil is given in Table VI together with the per cent of nitrogen in the crop. The second crop from the silt loam soil shows slight effects as a result of liming, but these small differences point to the neutral point as the best reaction. The per cent of nitrogen in the crop remains fairly constant, but with some tendency for the check pots to show the largest amount of nitrogen where the crop is the largest. The percentage recovery of nitrogen does not change greatly regardless of the amount of lime applied.

TABLE V  
THE EFFECT OF SOIL REACTION ON THE AVAILABILITY OF AMMONIUM SULFATE  
IN SANDY LOAM

Pot No.	Reaction of Soil as Pounds CaO	Mg. N Added	Yield, gm.	Average, gm.	Increase over Check	Per cent Increase	Per cent N	Total Mg. N	Average, gm.	Increase over Check	Per cent Increase	Per cent N Recovered
29	3000 lbs. acid....	0	2.5	.....	.....	.....	1.01	25.3	.....	.....	.....	.....
30	3000 lbs. acid....	0	2.2	2.35	.....	.....	1.00	22.0	23.7	.....	.....	.....
31	3000 lbs. acid....	310	4.0	.....	.....	.....	2.37	94.8	.....	.....	.....	.....
32	3000 lbs. acid....	310	3.1	3.55	1.20	51.1	2.90	89.9	92.4	68.7	289.9	22.2
33	2000 lbs. acid....	0	4.3	.....	.....	.....	1.20	51.6	.....	.....	.....	.....
34	2000 lbs. acid....	0	3.6	3.95	.....	.....	1.07	38.5	45.1	.....	.....	.....
35	2000 lbs. acid....	310	7.1	.....	.....	.....	1.77	125.7	.....	.....	.....	.....
36	2000 lbs. acid....	310	7.5	7.30	3.35	84.8	1.66	124.5	125.1	80.0	177.4	25.8
37	1000 lbs. acid....	0	3.5	.....	.....	.....	0.73	25.6	.....	.....	.....	.....
38	1000 lbs. acid....	0	4.0	3.75	.....	.....	0.98	39.2	32.4	.....	.....	.....
39	1000 lbs. acid....	310	6.9	.....	.....	.....	2.06	142.1	.....	.....	.....	.....
40	1000 lbs. acid....	310	8.0	7.45	3.70	98.7	1.72	137.6	139.9	107.5	331.8	34.7
41	Neutral .....	0	4.4	.....	.....	.....	1.14	50.2	.....	.....	.....	.....
42	Neutral .....	0	5.7	5.05	.....	.....	0.97	55.3	52.8	.....	.....	.....
43	Neutral .....	310	9.1	.....	.....	.....	1.59	144.7	.....	.....	.....	.....
44	Neutral .....	310	10.0	9.55	4.50	89.1	1.57	157.0	150.9	98.1	185.8	31.6
45	1000 lbs. alkaline	0	3.6	.....	.....	.....	0.98	35.3	.....	.....	.....	.....
46	1000 lbs. alkaline	0	6.2	4.90	.....	.....	1.00	62.0	48.7	.....	.....	.....
47	1000 lbs. alkaline	310	10.5	.....	.....	.....	1.48	155.4	.....	.....	.....	.....
48	1000 lbs. alkaline	310	10.1	10.30	5.40	110.2	1.35	136.4	145.9	97.2	199.5	31.3
49	2000 lbs. alkaline	0	6.4	.....	.....	.....	1.21	77.4	.....	.....	.....	.....
50	2000 lbs. alkaline	0	5.4	5.90	.....	.....	1.02	55.1	66.3	.....	.....	.....
51	2000 lbs. alkaline	310	11.9	.....	.....	.....	1.40	166.6	.....	.....	.....	.....
52	2000 lbs. alkaline	310	12.2	12.05	6.15	104.3	1.39	169.6	168.1	101.8	153.6	32.8
53	3000 lbs. alkaline	0	7.2	.....	.....	.....	0.86	61.9	.....	.....	.....	.....
54	3000 lbs. alkaline	0	5.3	6.25	.....	.....	0.91	48.2	55.2	.....	.....	.....
55	3000 lbs. alkaline	310	10.4	.....	.....	.....	1.47	152.9	.....	.....	.....	.....
56	3000 lbs. alkaline	310	12.2	11.30	5.05	80.8	1.35	164.7	163.8	108.6	196.7	35.0

In order to show better the relation of lime to crop yields and to the availability of ammonium sulfate, the results reported above are summarized in Tables VII, VIII, and IX, and shown graphically in figures 1 and 2. These give the results for two crops covering a period of approximately 6 months.

By referring to figure 1 it may be seen that the largest crop in the pots receiving no ammonium sulfate was always where the soil was markedly alkaline. In the case of the sand, lime had little effect because there was such a small amount of nitrogen present. In the sandy loam there is a gradual increase from 10.90 gm. at the highest acidity to 23.05 gm. at 2000 pounds alkalinity, and then a slight decrease with larger applications. In the silt loam, which was fairly fertile and probably had plenty of available nitrogen, lime shows some increase, but not marked. The most alkaline pots did not show any drop in yield as was noticed in the sandy loam.

TABLE VI  
THE EFFECT OF SOIL REACTION ON THE AVAILABILITY OF AMMONIUM SULFATE  
IN SILT LOAM

Pot No.	Reaction of Soil as Pounds CaO	Mg. N Added	Yield, gm.	Av. gm.	Increase over Check	Per cent Increase	Per cent N	Total Mg. N	Av. Mg. N	Increase over Check	Per cent Increase	Per cent N Recovered
57	4000 lbs. acid....	0	1.8	.....	.....	.....	1.13	20.3	.....	.....	.....	.....
58	4000 lbs. acid....	0	2.3	2.05	.....	.....	1.03	23.7	22.0	.....	.....	.....
59	4000 lbs. acid....	207	8.8	.....	.....	.....	1.14	100.3	.....	.....	.....	.....
60	4000 lbs. acid....	207	11.2	10.05	7.95	387.8	0.99	110.9	105.6	83.6	380.0	40.4
61	3000 lbs. acid....	0	3.6	.....	.....	.....	1.07	38.5	.....	.....	.....	.....
62	3000 lbs. acid....	0	3.1	3.35	.....	.....	1.01	31.3	34.9	.....	.....	.....
63	3000 lbs. acid....	207	10.2	.....	.....	.....	1.00	102.0	.....	.....	.....	.....
64	3000 lbs. acid....	207	10.3	10.25	6.90	205.9	1.06	109.2	105.6	70.7	202.6	34.1
65	2000 lbs. acid....	0	3.4	.....	.....	.....	1.20	40.8	.....	.....	.....	.....
66	2000 lbs. acid....	0	2.3	2.85	.....	.....	1.08	34.8	32.8	.....	.....	.....
67	2000 lbs. acid....	207	10.1	.....	.....	.....	0.97	97.8	.....	.....	.....	.....
68	2000 lbs. acid....	297	9.5	9.80	6.95	243.9	1.18	112.1	105.0	72.2	220.1	34.9
69	1000 lbs. acid....	0	3.0	.....	.....	.....	1.09	32.7	.....	.....	.....	.....
70	1000 lbs. acid....	0	2.6	2.80	.....	.....	1.18	30.7	31.7	.....	.....	.....
71	1000 lbs. acid....	207	9.5	.....	.....	.....	0.98	93.1	.....	.....	.....	.....
72	1000 lbs. acid....	207	11.0	10.25	7.45	266.1	0.88	96.8	99.9	68.2	215.1	33.0
73	Neutral .....	0	2.6	.....	.....	.....	1.16	30.2	.....	.....	.....	.....
74	Neutral .....	0	3.0	2.80	.....	.....	1.28	38.4	34.3	.....	.....	.....
75	Neutral .....	207	11.9	.....	.....	.....	1.00	119.0	.....	.....	.....	.....
76	Neutral .....	207	14.1	13.00	10.20	364.3	0.86	121.3	120.2	83.9	244.6	40.5
77	1000 lbs. alkaline	0	2.8	.....	.....	.....	1.12	31.4	.....	.....	.....	.....
78	1000 lbs. alkaline	0	2.7	2.75	.....	.....	1.18	31.9	31.7	.....	.....	.....
79	1000 lbs. alkaline	207	15.1	.....	.....	.....	0.97	146.5	.....	.....	.....	.....
80	1000 lbs. alkaline	207	11.3	13.20	10.45	380.0	0.93	105.1	125.8	94.1	296.8	45.5
81	2000 lbs. alkaline	0	3.3	.....	.....	.....	1.24	40.9	.....	.....	.....	.....
82	2000 lbs. alkaline	0	3.4	3.35	.....	.....	1.27	42.2	41.6	.....	.....	.....
83	2000 lbs. alkaline	207	11.1	.....	.....	.....	0.98	108.8	.....	.....	.....	.....
84	2000 lbs. alkaline	207	13.3	12.20	8.85	264.2	1.00	133.0	120.9	79.3	190.6	38.3
85	3000 lbs. alkaline	0	3.5	.....	.....	.....	1.25	43.8	.....	.....	.....	.....
86	3000 lbs. alkaline	0	.....	3.50	.....	.....	.....	.....	43.8	.....	.....	.....
87	3000 lbs. alkaline	207	12.8	.....	.....	.....	0.95	121.6	.....	.....	.....	.....
88	3000 lbs. alkaline	207	12.9	12.85	9.35	267.1	1.00	129.0	125.3	81.5	186.1	39.4

Figure 2 brings out the differences between the three soils due to reaction in the presence of ammonium sulfate. Small amounts of lime produced nearly as good results as where enough was applied to neutralize all of the acidity. With large amounts of lime there is a slight dimin-



ution in the yields. In the two heavier soils small amounts of lime also produced nearly as large an increase in crop as did the larger amounts.

Tables VII, VIII, and IX give the per cent of nitrogen and the total recovery in the crop. In practically all cases the total amount removed from each pot by the two crops bears a direct ratio to the crop yields. As one increases the other also increases, and for this reason it is not necessary to show the results diagrammatically.

TABLE VII  
SUMMARY—THE EFFECT OF SOIL REACTION ON THE AVAILABILITY OF  
AMMONIUM SULFATE IN SAND

Pot No.	Reaction of Soil as Pounds CaO	Mg. N Added	Yield, gm.	Av. gm.	Increase over Check	Per cent Increase	Total Mg. N	Av. Mg. N	Increase over Check	Per cent Increase	Per cent N Recovered
1	3000 lbs. acid....	0	4.2	.....	.....	.....	49.9	.....	.....	.....	.....
2	3000 lbs. acid....	0	4.8	4.50	.....	.....	50.3	50.10	.....	.....	.....
3	3000 lbs. acid....	310	4.9	.....	.....	.....	97.0	.....	.....	.....	.....
4	3000 lbs. acid....	310	4.2	4.55	0.05	1.11	86.4	91.70	41.60	83.2	26.8
5	2000 lbs. acid....	0	4.8	.....	.....	.....	64.1	.....	.....	.....	.....
6	2000 lbs. acid....	0	5.1	4.95	.....	.....	64.4	64.25	.....	.....	.....
7	2000 lbs. acid....	310	12.5	.....	.....	.....	195.6	.....	.....	.....	.....
8	2000 lbs. acid....	310	10.0	11.25	6.30	127.3	172.9	184.25	120.00	186.8	60.3
9	1000 lbs. acid....	0	5.2	.....	.....	.....	64.1	.....	.....	.....	.....
10	1000 lbs. acid....	0	5.0	5.10	.....	.....	70.5	67.30	.....	.....	.....
11	1000 lbs. acid....	310	12.6	.....	.....	.....	182.0	.....	.....	.....	.....
12	1000 lbs. acid....	310	13.6	13.10	8.00	156.9	187.7	184.85	117.55	174.6	56.3
13	Neutral .....	0	6.4	.....	.....	.....	63.6	.....	.....	.....	.....
14	Neutral .....	0	5.5	5.95	.....	.....	59.9	61.75	.....	.....	.....
15	Neutral .....	310	14.0	.....	.....	.....	178.8	.....	.....	.....	.....
16	Neutral .....	310	10.9	12.45	6.50	109.2	156.3	167.55	105.80	171.3	55.2
17	1000 lbs. alkaline	0	5.6	.....	.....	.....	56.9	.....	.....	.....	.....
18	1000 lbs. alkaline	0	5.9	5.75	.....	.....	60.1	58.50	.....	.....	.....
19	1000 lbs. alkaline	310	11.7	.....	.....	.....	132.9	.....	.....	.....	.....
20	1000 lbs. alkaline	310	10.5	11.10	5.35	93.0	137.9	135.40	76.90	131.4	42.4
21	2000 lbs. alkaline	0	6.4	.....	.....	.....	66.1	.....	.....	.....	.....
22	2000 lbs. alkaline	0	6.5	6.45	.....	.....	62.5	64.30	.....	.....	.....
23	2000 lbs. alkaline	310	10.0	.....	.....	.....	140.9	.....	.....	.....	.....
24	2000 lbs. alkaline	310	10.9	10.45	4.00	62.0	139.9	140.40	76.10	118.3	38.2
25	3000 lbs. alkaline	0	4.1	.....	.....	.....	50.1	.....	.....	.....	.....
26	3000 lbs. alkaline	0	7.5	5.80	.....	.....	86.0	68.05	.....	.....	.....
27	3000 lbs. alkaline	310	10.9	.....	.....	.....	126.1	.....	.....	.....	.....
28	3000 lbs. alkaline	310	11.5	11.20	5.40	93.1	142.1	134.10	66.05	97.1	31.3

The percentage recovery of the nitrogen applied increases with the smaller applications of lime and then usually decreases. This decrease may be misleading unless we remember that, except in the sand, the check pots showed more of a tendency to increase as the lime content increased than did the pots receiving ammonium sulfate. This increase of the checks naturally lowers the percentage recovery of the nitrogen applied.

## DISCUSSION

From the practical standpoint the above data would seem to indicate that it is not economical to use large quantities of lime in one application to soils even though they are strongly acid. A small application produced nearly as large a crop yield on the sandy loam and silt loam soils as did larger amounts, and even better results in the case of the sand. Where large amounts of lime are applied at one application the

TABLE VIII  
SUMMARY—THE EFFECT OF SOIL REACTION ON THE AVAILABILITY OF  
AMMONIUM SULFATE IN SANDY LOAM

Pot No.	Reaction of Soil as Pounds CaO	Mg. N Added	Yield, gm.	Av. gm.	Increase over Check	Per cent Increase	Total Mc. N	Av. Mc. N	Increase over Check	Per cent Increase	Per cent N Recovered
29	3000 lbs. acid....	0	10.7	.....	.....	.....	86.0	.....	.....	.....	.....
30	3000 lbs. acid....	0	11.1	10.90	.....	.....	92.3	89.15	.....	.....	.....
31	3000 lbs. acid....	620	23.6	.....	.....	.....	359.4	.....	.....	.....	.....
32	3000 lbs. acid....	620	19.6	21.60	10.70	98.2	319.3	339.35	250.20	280.6	40.3
33	2000 lbs. acid....	0	14.7	.....	.....	.....	125.4	.....	.....	.....	.....
34	2000 lbs. acid....	0	11.6	13.15	.....	.....	108.1	116.75	.....	.....	.....
35	2000 lbs. acid....	620	26.5	.....	.....	.....	368.2	.....	.....	.....	.....
36	2000 lbs. acid....	620	29.0	27.75	14.60	111.0	406.2	387.10	270.35	231.5	43.6
37	1000 lbs. acid....	0	15.2	.....	.....	.....	136.8	.....	.....	.....	.....
38	1000 lbs. acid....	0	15.0	15.10	.....	.....	127.2	132.00	.....	.....	.....
39	1000 lbs. acid....	620	31.9	.....	.....	.....	439.6	.....	.....	.....	.....
40	1000 lbs. acid....	620	30.0	30.95	15.85	104.9	406.0	422.80	290.80	220.3	46.9
41	Neutral .....	0	20.9	.....	.....	.....	175.6	.....	.....	.....	.....
42	Neutral .....	0	20.0	20.45	.....	.....	168.3	171.95	.....	.....	.....
43	Neutral .....	620	30.3	.....	.....	.....	426.7	.....	.....	.....	.....
44	Neutral .....	620	31.2	30.75	10.30	50.4	434.7	430.70	258.75	150.5	41.7
45	1000 lbs. alkaline	0	19.4	.....	.....	.....	182.2	.....	.....	.....	.....
46	1000 lbs. alkaline	0	21.4	20.40	.....	.....	203.4	192.80	.....	.....	.....
47	1000 lbs. alkaline	620	33.6	.....	.....	.....	425.7	.....	.....	.....	.....
48	1000 lbs. alkaline	620	31.6	32.60	12.20	59.8	439.6	432.65	239.85	124.4	38.7
49	2000 lbs. alkaline	0	22.9	.....	.....	.....	252.3	.....	.....	.....	.....
50	2000 lbs. alkaline	0	23.2	23.05	.....	.....	220.6	236.45	.....	.....	.....
51	2000 lbs. alkaline	620	32.2	.....	.....	.....	436.6	.....	.....	.....	.....
52	2000 lbs. alkaline	620	28.7	30.45	7.40	32.1	451.8	440.20	207.75	87.9	35.1
53	3000 lbs. alkaline	0	21.6	.....	.....	.....	241.9	.....	.....	.....	.....
54	3000 lbs. alkaline	0	20.2	20.90	.....	.....	233.0	237.45	.....	.....	.....
55	3000 lbs. alkaline	620	29.8	.....	.....	.....	474.9	.....	.....	.....	.....
56	3000 lbs. alkaline	620	33.5	31.65	10.75	51.4	490.6	482.75	245.30	104.1	39.5

loss is greater and the expense of the lime itself is great. Perhaps by making smaller applications but more frequently, less lime would serve the purpose. The organic nitrogen would be made available only as the crop needed it and there would be less chance of oxidizing the soil organic matter to such an extent as to leave the soil in a worse condition than before lime was used. Perhaps with some crops, such as the legumes, much larger applications of lime would be required than was found to be necessary for buckwheat.

From the standpoint of the utilization of the nitrogen applied, the results already given show that the heavier the soil the less effect calcium oxide has in increasing the availability of the ammonium sulfate. A slight acidity in a sandy soil would no doubt cause a greater injury to crops than three or four times that acidity in the heavier soil. Buckwheat seems to use ammonium sulfate almost as well in the heavier soils

TABLE IX  
SUMMARY—THE EFFECT OF SOIL REACTION ON THE AVAILABILITY OF  
AMMONIUM SULFATE IN SILT LOAM

Plot No.	Reaction of Soil as Pounds CaO	Mg. N Added	Yield, gm.	Av. gm.	Increase over Check	Per cent Increase	Total Mg. N	Av. Mg. N	Increase over Check	Per cent Increase	Per cent N Recovered
57	4000 lbs. acid....	0	16.2	.....	.....	.....	144.1	.....	.....	.....	.....
58	4000 lbs. acid....	0	16.2	16.20	.....	.....	144.6	144.35	.....	.....	.....
59	4000 lbs. acid....	414	30.7	.....	.....	.....	350.0	.....	.....	.....	.....
60	4000 lbs. acid....	414	32.6	31.65	15.45	95.3	360.3	355.15	210.80	146.0	50.9
61	3000 lbs. acid....	0	18.2	.....	.....	.....	165.5	.....	.....	.....	.....
62	3000 lbs. acid....	0	17.1	17.65	.....	.....	189.5	177.50	.....	.....	.....
63	3000 lbs. acid....	414	32.9	.....	.....	.....	354.0	.....	.....	.....	.....
64	3000 lbs. acid....	414	31.9	31.40	13.75	77.9	383.5	368.75	191.25	107.7	46.2
65	2000 lbs. acid....	0	19.9	.....	.....	.....	177.8	.....	.....	.....	.....
66	2000 lbs. acid....	0	16.8	18.35	.....	.....	168.4	173.10	.....	.....	.....
67	2000 lbs. acid....	414	34.2	.....	.....	.....	377.4	.....	.....	.....	.....
68	2000 lbs. acid....	414	32.7	33.45	15.10	82.3	388.2	382.80	209.70	121.1	50.7
69	1000 lbs. acid....	0	20.0	.....	.....	.....	156.8	.....	.....	.....	.....
70	1000 lbs. acid....	0	18.6	19.30	.....	.....	187.5	172.15	.....	.....	.....
71	1000 lbs. acid....	414	33.5	.....	.....	.....	383.5	.....	.....	.....	.....
72	1000 lbs. acid....	414	31.7	32.60	13.30	68.9	346.3	364.90	192.75	111.9	46.6
73	Neutral .....	0	19.7	.....	.....	.....	197.8	.....	.....	.....	.....
74	Neutral .....	0	16.9	18.30	.....	.....	186.5	192.15	.....	.....	.....
75	Neutral .....	414	36.0	.....	.....	.....	391.3	.....	.....	.....	.....
76	Neutral .....	414	34.7	35.35	17.05	93.2	420.0	405.65	213.50	111.1	51.6
77	1000 lbs. alkaline	0	21.0	.....	.....	.....	195.2	.....	.....	.....	.....
78	1000 lbs. alkaline	0	20.7	20.85	.....	.....	217.3	206.25	.....	.....	.....
79	1000 lbs. alkaline	414	33.1	.....	.....	.....	407.5	.....	.....	.....	.....
80	1000 lbs. alkaline	414	34.3	33.70	12.85	61.6	392.6	400.05	193.80	94.0	46.8
81	2000 lbs. alkaline	0	20.1	.....	.....	.....	187.1	.....	.....	.....	.....
82	2000 lbs. alkaline	0	22.4	21.25	.....	.....	217.0	202.05	.....	.....	.....
83	2000 lbs. alkaline	414	34.7	.....	.....	.....	394.4	.....	.....	.....	.....
84	2000 lbs. alkaline	414	37.9	36.30	15.05	78.2	412.4	403.40	201.35	99.7	48.6
85	3000 lbs. alkaline	0	26.5	.....	.....	.....	289.9	.....	.....	.....	.....
86	3000 lbs. alkaline	0	.....	26.50	.....	.....	.....	289.90	.....	.....	.....
87	3000 lbs. alkaline	414	35.2	.....	.....	.....	433.0	.....	.....	.....	.....
88	3000 lbs. alkaline	414	37.6	36.40	9.90	37.3	437.8	435.40	145.50	50.2	35.1

in the absence of lime as in its presence. By referring to the summary tables it may be seen that wholly from the standpoint of percentage recovery of nitrogen or, in other words, availability, lime is not really essential, or if so, only in very small amounts. While it is true that liming an acid soil does increase the crop growth, yet the recovery of nitrogen is just as likely to be decreased as increased. This is partially explained

by the stimulating effect of the lime on bacterial activities resulting in the making available of the organic nitrogen to such an extent as to supply the needs of the crop without the use of ammonium sulfate or other artificial fertilizers. Still another factor to be considered is the analysis of the crop. Quite often, as occurred in the case of the sandy soil, the per cent of nitrogen in the crop receiving ammonium sulfate but no lime is larger than that grown in the presence of lime. In this case the smaller crop is higher in protein and shows high utilization of the plant-food applied.

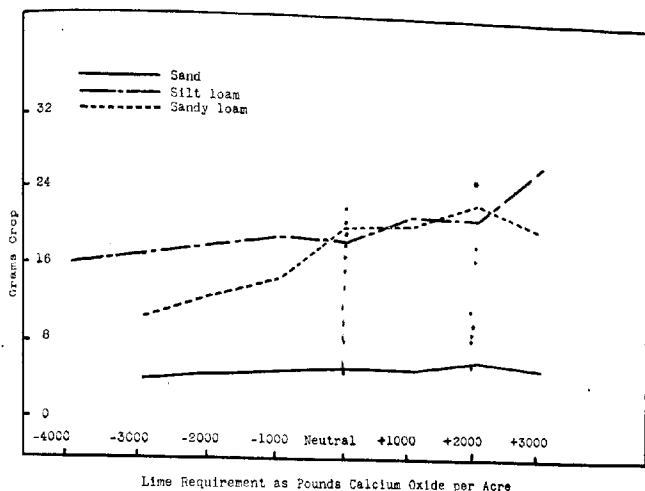


Fig. 1.—Yields of buckwheat in relation to soil reaction in the absence of ammonium sulfate.

These results show, then, that buckwheat either takes up nitrogen in the form of ammonia or that nitrification proceeds to an appreciable extent in acid soils. While it has been reported that buckwheat can not utilize ammonia, the mere fact that the per cent of nitrogen in the crop from the more acid soils is higher than from the alkaline soils would indicate that ammonia was used. Perhaps the acidity alone is the factor which caused the storing up of such large amounts of nitrogen in the tissues. On the other hand, if the plants used only nitrate nitrogen, then the ammonium sulfate must have been nitrified as rapidly in the acid soils as it was needed. In the limed soil there are undoubtedly more nitrates formed but the bacterial activities are also greatly increased, making necessary a greater assimilation by these lower forms, and possibly less nitrogen is actually available for the crop than in the acid soil.

The yield of dry matter on the acid soils is low, not because of lack of available nitrogen, phosphorous, or potassium, but probably because of the unfavorable medium in which the plants must grow.

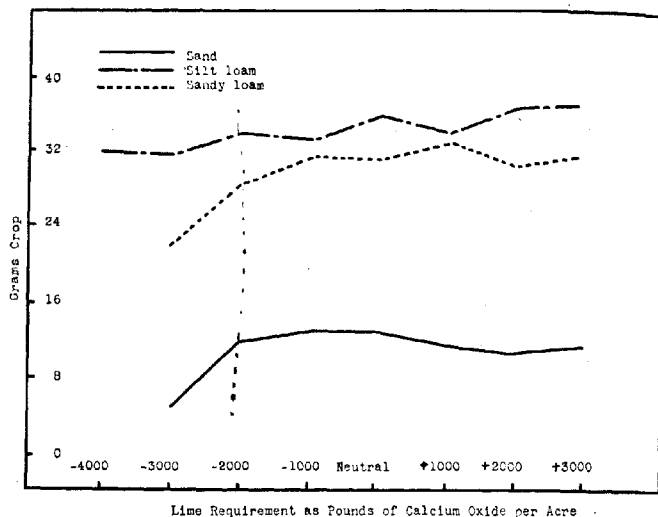


Fig. 2.—Yields of buckwheat in relation to soil reaction in the presence of ammonium sulfate.

#### SUMMARY

The results reported in this paper may be summarized as follows:

1. Small applications of calcium oxide produced practically as large yields of buckwheat as where enough lime was added to neutralize all of the acidity or make the soil distinctly alkaline.
2. Buckwheat grown on the more acid soils usually showed a higher per cent of nitrogen but the total yield of the crop was smaller. For this reason the recovery of the nitrogen from the more acid soils in many cases was as great as, or even greater than that from the alkaline soils.
3. The beneficial effects of calcium oxide on acid soils were much more noticeable on the sandy soils than on the silt loam.
4. The addition of calcium oxide to acid soils allows the soil nitrogen to be made available to such an extent as to supply the needs of the crop. Hence, the use of ammonium sulfate on alkaline soils may produce a smaller increase in yield over checks than where the same amount of the fertilizer is added to an acid soil.
5. Buckwheat is able to utilize the nitrogen from ammonium sulfate at an acidity of 3,000 to 4,000 pounds of calcium oxide per acre. The nitrogen is either taken up as ammonia or else nitrification proceeds to a considerable extent in the presence of the acid.

